RELATIONAL AND INTRAITEM PROCESSING IN THE ACQUISITION AND RETENTION OF A COGNITIVE SKILL

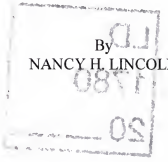

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TABLE OF CONTENTS

page

DEDICATION iv

ACKNOWLEDGMENTS v

ABSTRACT vi

INTRODUCTION 1
Distribution of Practice 4
Spacing Effect Theories 7
Contextual Interference 9
Early Theories 10
Relational Processing Theory 12
Intraitem Processing Theory 13
Domains of Contextual Interference 14
Motor learning 15
Verbal learning 16
Cognitive skills 17
The Present Investigation 18

EXPERIMENT ONE 22

Method 25
Participants 25
Materials and Apparatus 25
Design 26
Procedure 26
Acquisition 26
Retention 28
Results and Discussion 28
Acquisition 29
Retention 31
Figures 37

EXPERIMENT TWO 41

Method 42
Participants 42

Materials and Apparatus 43
Design 43
Procedure 43
Results and Discussion 44
Acquisition 44
Retention 46
Relational Processing 48
Acquisition 48
Retention 50
Figures 55

EXPERIMENT THREE 61

Method 66
Participants 66
Materials and Apparatus 67
Design 67
Procedure 67
Results and Discussion 68
Acquisition 68
Retention 70
Figures 77

GENERAL DISCUSSION 82

APPENDIX A SYMBOLS AND RULES FOR EXPERIMENT 1 93

APPENDIX B SYMBOLS AND RULES FOR EXPERIMENT 2 94

APPENDIX C PREDICTED AND ACTUAL FUNCTIONS FOR EXPERIMENT 3 95

REFERENCES 96

BIOGRAPHICAL SKETCH 101

DEDICATION

This dissertation is dedicated to my father, A. K. "Abe" Lincoln, who was taken prematurely from this world in September 2000. I thank him for his encouragement and support throughout my academic years. He always teased that I would be an eternal student, but now I can answer, "Yes, I am finally done!"

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RELATIONAL AND INTRAITEM PROCESSING IN THE
ACQUISITION AND RETENTION OF A COGNITIVE SKILL

By

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Major Department: Psychology

The *contextual interference effect* occurs when randomly-varied practice on a set of items results in poorer performance than does practice blocked by items during acquisition, but better subsequent long-term retention of the information that has been learned. Three experiments were conducted to see if contextual interference effects were to be found in a novel, complex cognitive skill involving unfamiliar symbols and computational rules, and to evaluate several proposed explanations of the effect. Intraitem processing theories focus on the reconstruction of to-be-learned items from memory during acquisition, whereas interitem or relational processing theories focus on contrasts and comparisons between items during learning. Participants learned sets of unique or related Kanji characters mapped onto sequential mathematical rules in various practice schedules (random, blocked, blocked with an intervening task, and semi-random) and were then given a retention test 48 hours later. A strong contextual interference effect was found in all three experiments, extending the current literature to the higher-level

learning of cognitive skills. Marginal effects of relational processing were found. The claim that a blocked-plus-intervening-task schedule could replicate the demands and workload of a random schedule was not supported. Differences amongst groups that learned the rules one at a time, or in groups of two, three, or six, are discussed in terms of intraitem mechanisms of displacement, and of varying levels of proactive interference, during acquisition. Theoretical explanations are adopted from the literature on the distribution of practice (e.g., deficient-processing theories) to understand underlying processes of random and blocked practice schedules. It is speculated that relational factors may play more of a role in learning large bodies of organized facts or procedures.

INTRODUCTION

In this dissertation, three experiments are described that explore how variations in the sequence and distribution of practice during acquisition of a set of unfamiliar mathematical rules affects subsequent retention of those rules. Explanations for these effects that focus on relations among the rules, on the one hand (relational processing), and on the quality of encoding individual rules (intraitem processing), on the other, are contrasted.

It is commonly thought that performance during or immediately after training (or *acquisition*) is a valid indicator of the amount of learning that had taken place during that training. This concept is implicit in many applied training programs in use today; with skills being taught and practiced in ways that seek to maximize performance during acquisition. However, research on the details of events during practice, such as the distribution of practice over time and the sequencing of specific conditions of practice, suggest that the goals of maximizing long-term retention and generalizability of skills may be best met with practice conditions that actually produce less than ideal performance during learning or training.

This somewhat counterintuitive claim is of practical as well as theoretical importance. In formal training situations, it is often the case that trainees are exposed to a substantial amount of information in a short period of time, and tested on their "retention" of the skills and knowledge they have just learned immediately after training has ceased. This contrasts to many everyday situations in which a skill is acquired

informally; here, people often receive practice in a random, intermittent and variable fashion, and may not have the opportunity to use learned skills for quite some time after acquisition. For example, in their cross-sectional study of the retention of Spanish learned in high school, Bahrick and Phelps (1987) found that most of their several hundred participants did not practice or rehearse any of their Spanish knowledge in the years that followed their initial training. This may be true even for skills and knowledge that are relevant to the ongoing professional activities of the learner. For example, the medical practitioner may not encounter a particular set of diagnostic symptoms until years after studying it as a medical student. For these reasons, it seems ecologically important to study retention over longer periods of time than is typically done in the learning laboratory, where the practice has been to assess retention of a skill shortly after acquisition, or at most several hours later.

Early learning theorists made mention of conditions that appeared to retard acquisition, but enhance long-term retention (e.g., Estes, 1955; Hull, 1942), perhaps because in that tradition, only effects that had some permanence across long periods of time would be classified as "learning" (Schmidt & Bjork, 1992). In the behavioral literature, learning has been viewed as having three main components: behavioral change, practice or experience, and permanency (Hilgard & Bower, 1975). As the information-processing approach to cognition became more widespread, cognitive psychologists began to view learning less as a passive strengthening of a behavior and more as an active and constructive process (Atkinson & Shiffrin, 1968; Neisser, 1967). Mental activities and cognitive processing, such as pattern recognition, imagery and attention, were incorporated into the definition. Neisser's (1967) classic definition of learning involves processes by which the input from the various senses is "transformed, reduced,

elaborated, stored, recovered, and used" (p. 5). For the behaviorists, then, a change in behavior represented learning; while for the cognitive psychologist, the change was in the knowledge structures or cognitive processes (which ultimately could lead to the behavior change). From either perspective, some type of permanency is crucial to the definition of learning. The distinction between temporary and relatively permanent effects of manipulations during learning is now being investigated once again in various studies on the variability of practice during acquisition.

Of course, an overall positive relation is to be expected between amount of learning and subsequent retention. Past research by Bahrick (1984, 1979; see also Conway, Cohen and Stanhope, 1991), for example, showed that achievement at the end of training (as assessed by final exam grades) was a strong predictor of the degree of very long-term retention of academic knowledge and skills. The classic acquisition function first described by Ebbinghaus (1885/1913) clearly shows this systematic relationship between amount of practice and subsequent memory, in this case for lists of nonsense syllables (Ebbinghaus' retention interval was typically 24 hours).

But while performance at the end of the acquisition period may predict the *general* level of retention several years later, the way in which the material was learned can also have a substantial effect on long-term retention. I will review two closely related aspects of how the scheduling of practice events can suppress or retard performance during acquisition, but boost, sometimes substantially, long-term retention of the skill: spacing rather than "massing" practice (the *distribution of practice* effect); and randomizing rather than blocking presentation of specific groups or categories of events during practice (the *contextual interference* effect).

Distribution of Practice

In today's educational system, "cramming" the night before an exam seems to be the rule rather than the exception. Students seem to feel that if they study all the material at once, especially right before the test, they will be able to remember the information better. Research has shown that this is not typically the case, however.

There has been an enormous amount of research on the effects of the distribution of practice on the long-term retention of knowledge. Spacing or distributing practice over time commonly leads to better retention, compared to practicing in one uninterrupted session (known as *massed practice*). The *spacing effect* is one of the most robust and reliable phenomena in experimental psychology, and it usually leads to sizeable differences in retention performance. In fact, this phenomenon was known as early as 1885. Ebbinghaus (1885/1913) conducted a variety of memory experiments, with himself as the sole subject, and concluded that

> With any considerable number of repetitions a suitable distribution of them over a space of time is decidedly more advantageous than the massing of them at a single time. (p. 89)

Early educational research also pointed to the advantageous nature of distributing practice over time. In his guide to teachers and students, William James (1901) advised teachers that "it is better to repeat an association on many days, than again and again on just a few days" (p. 129). Confirming James' theory, Pyle (1913) reported that school children who were drilled in mathematics once a day for ten days had a marked improvement in recall of addition facts over those who were drilled twice a day for five days.

When the retention test is immediate, massed practice may yield somewhat better performance than spaced. For example, Keppel (1964) had participants learn lists of paired-associates in either a massed or distributed practice schedule. Massed practice conditions produced superior performance during learning; an immediate test revealed these participants recalled 98% of the associates, compared to the 90% recall rate in the distributed condition. Based on the immediate-test results, one might conclude that massed practice conditions produce more "learning" than spaced practice. Yet long-term retention results confirm the opposite. In Keppel's (1964) study, a retention test eight days after the final learning block revealed distributed practice conditions yielded a recall rate of 72%, as compared to an 8% recall rate for the massed practice group. Significant differences between massed and spaced retention performance were seen as soon as 24 hours after the acquisition period.

Spacing effects have been found in virtually all traditional verbal learning tasks, including paired-associate learning, recall and recognition (for a review, see Hintzman, 1974). In an illustrative study by Dempster (1987, Exp. 3), participants were asked to learn 38 uncommon English words and their definitions. Each word and its definition were presented three times, either with each repetition separated by all 37 of the other words, or massed together (three times in succession). Though recall rate was generally low overall, spaced presentations resulted in significantly higher levels of vocabulary learning by the end of training ($\underline{M}$ = 22%) than did massed practice ($\underline{M}$ = 13%).

In a more everyday setting, Bahrick, Bahrick, and Wittlinger (1975) studied the retention of the names and faces of former high school classmates after several decades and found that retention was high overall. This contrasted to the retention of the names and faces of former students by professors, which was dismally low. They posited that

this difference was due to the greater amounts of time and opportunity the students had for learning and rehearsing the names. The classmates had four years to learn each other's names and faces, and numerous opportunities for rehearsal, whereas the study with professors was based on students that had been in one of their courses, which only amounted to about 10 weeks in the classroom. This could be considered a real-world equivalent to spaced vs. massed practice of the student's names, though inherent individual differences between college students and professors, as well as total number of opportunities for practice, might have played a role as well. Bahrick and Hall (1991) also investigated the long-term retention of mathematics learned in high school. They found that those who had gone on to college-level math retained their high school math skills better than those who had not. This suggests that if practice is extended over a longer amount of time, or if opportunities for rehearsal are given, retention will be greater than if the same material is studied over a shorter time or if no extra rehearsals are given.

A verbal learning study by Bahrick and Phelps (1987) also confirms the spacing effect hypothesis in a more controlled environment. They found substantially enhanced performance on an eight-year retention test for participants who learned Spanish-English vocabulary word pairs with a 30-day interval between relearning sessions, as opposed to those with only a one-day or zero-day intersession interval. The recall probability associated with the 30 day interval was roughly 2.5 times the probability of recall associated with the zero (massed) interval.

Spacing effects have also been demonstrated in free recall (Shaughnessy, Zimmerman, & Underwood, 1972), concept and rule learning (Gay, 1973), learning of mathematics concepts (Bahrick & Hall, 1991) and text processing (Dempster, 1986; cited in Dempster, 1996). Interestingly, Greene (1989) found that spacing effects occurred

even when his participants were not aware they were going to be tested. In an *incidental memory* paradigm, participants are shown various stimuli either passively, or they are asked to do some unrelated task using the stimuli. However, they are not aware that they will be tested on the materials afterwards. Spacing effects seem to rely on a very basic mechanism, as they have been found with this kind of incidentally learned material (Greene, 1989), and even with preschoolers and infants (Toppino, 1991).

Spacing Effect Theories

Two main classes of theories have been proposed to explain these spacing effects. *Deficient-processing* (or *memory reconstruction*) theories (e.g., Cuddy & Jacoby, 1982; Jacoby, 1978; Hintzman, 1976; Bregman, 1967) claim that the second occurrence of an item repeated in massed fashion receives less processing, or shallower processing, than does the second occurrence of a spaced item.

The deficient-processing account of spacing effects fits well into the broader framework of levels-of-processing theory, which had been introduced by Jacoby's colleagues a few years earlier (Craik & Lockhart, 1972). Jacoby (1978, Cuddy & Jacoby, 1982) suggests that when an item is repeated very soon after its initial presentation, one does not need to process it to the same extent as one would process the first presentation. Spacing over time forces active reprocessing or cognitive reconstruction in working memory for each repeated item, due to the less accessible memory of the previous repetition. Recall is then a function of the amount or quality of processing the item(s) receives.

For example, Jacoby (1978) varied the spacing of repetitions of problems in a problem-solving task, and found that if repetitions of identical problems were in close proximity, then learners could retrieve the prior solution rather than solving the problem

again. Remembering the previous presentation thus allowed the participant to reduce the processing demands for the repetition. However, with spaced repetition, the solution was less likely to be remembered, the problem solved by application of an algorithm, and ultimate retention, and measured by a delayed test on similar problems, is improved. In an influential paper on repetition memory, Melton (1967) described the effect of spacing repetitions as quite paradoxical, in that it seems to suggest that forgetting material between repetitions actually helps memory.

Consistent with the deficient-processing hypothesis, Shaughnessy, Zimmerman, and Underwood (1972) and Rose (1984) found that reaction times to respond to repeated items increased over spacing; participants spent more time processing spaced repetitions than massed repetitions. Rose (1984) had participants answer simple yes/no questions about various words, which were presented on several occasions in different contexts. Their reaction times to answer the simple questions were recorded, and then they were to estimate the frequency of the repeated words. The results revealed increased reaction time, as well as more accurate frequency judgments, as spacing increased.

Contextual variability (or encoding variability) theories (e.g., Glenberg, 1979; Gartman & Johnson, 1972) assume that spacing facilitates memory performance because it increases the number of distinctive retrieval cues for a repeated item. As the lag between presentations increases, the total amount of contextual information that is stored also increases. Thus, as the number of different or specific encodings increases, the number of potential retrieval routes also increases. Typical support for this theory comes from studies where some aspect of the encoding context is controlled, and spacing effects are reduced or eliminated. For example, McFarland, Rhodes and Frey (1979) used varied semantic contexts that accompanied massed repetitions, and were able to eliminate the

spaced-repetition advantage. Nonetheless, there have been a number of failures to produce such effects, as well as cases where contextual change across repetitions actually led to poorer ultimate recall (e.g., Dempster, 1989). Dempster (1996) concluded that contextual variability "cannot be considered a general explanation for the spacing effect" (p. 326). Similarly, Greene (1989) has proposed that both deficient processing and contextual variability theories are needed to sufficiently explain spacing effects.

Contextual Interference

The literature on spacing effects has confirmed the claims that one's performance during or right after acquisition is not always a good indicator of one's performance over a longer period of time. An apparently closely related phenomenon which produces retarded performance during acquisition, yet superior performance at a later retention test, has come to be called *contextual interference*. The contextual interference effect has been shown to occur when several items, skills, or procedures must be learned. In many cases, high levels of interference can be produced by practicing the different to-be-learned items in a varied or random order. This can be contrasted with practicing the same skills in blocks or groups, where the same item is studied on successive practice trials. With *random* practice of skills, performance during the learning phase is typically depressed; however, performance on later transfer or retention tests is better than for those conditions with lower levels of interference during acquisition (i.e., blocked practice). The term *contextual interference* refers, then, to the lower performance for a given item during acquisition when it is in the context of dissimilar material (as with random presentation) than in the context of similar or identical material (as with blocked presentation).

Early Theories

The roots of contextual interference can be traced back to Battig (1972) and his notion of *intratask interference*. He advocated the concept that the larger the amount of interference from other items (and hence, more difficulty) at the time of learning, the greater the subsequent long-term retention and transfer of the information that has been learned. Battig (1979) distinguished between two different bases for this interference, *contextual variety* and *similarity*. Originally, Battig had focused on similarities between items to-be-learned as the cause of heightened difficulty during acquisition. *Similarity* refers to the confusability or semantic resemblance of the items to be learned. If the conditions are the same for both the acquisition and test phases, then high item similarity should yield a high between-item interference effect. Participants would need to have a more elaborate schema for each item to-be-learned in order to discriminate it from the other highly similar items. Increased interitem similarity induces additional elaborative processing which aids in forming an organized and discriminative long-term memory structure (Battig, 1979). This necessarily would require more working memory capacity, as well as overall attentional resources, which would lead to a longer amount of time to master the material during the learning phase. It is this additional processing that strengthens the long-term memory structure and leads to increased performance on tests of retention. Battig noted, however, that this form of interference was limited in that conditions during learning must be replicated at test.

Battig's concept of intratask interference was originally conceived as being localized in the task itself, but later studies (Battig, 1979; Einstein, 1976) indicated broader and more extraneous aspects of the interference. For example, Einstein (1976) created task interference by asking participants to perform an additional processing task

during learning. Participants were to learn a list of auditorily presented words, while concurrently viewing and responding to another list of words. The degree of interference was manipulated by varying the relatedness of the visually presented words to the auditory list. He found that the interfering material lengthened learning time and produced more errors, but it subsequently increased memory performance after 5 weeks for the material learned under the related interference conditions. Battig (1979) later termed this phenomenon "contextual interference," to indicate the important roles of contextual factors and other external processing activities in determining interference in learning and retention.

Battig (1979) claimed that this broader sense of interference included internal factors such as the task and the items themselves, as well as external factors such as the variability of practice and other concurrent processing activities. Changes in context across trials of learning, or between the acquisition and retention phases, were labeled *contextual variety*. These contextual changes increase the number of distinctive retrieval routes, and should yield subsequent superior performance on a retention (or transfer) test. Battig suggested that high contextual variety results in multiple encoding processes--different types of encoding processes, as well as the use of different types of processes for performing the same tasks but in different contexts. Similar to contextual variability theories of spacing effects, changes in the learning context across trials increase the number of distinctive retrieval cues as well as the total amount of contextual information that is stored. Echoing the deficient-encoding account of spacing effects, Battig also suggested that this type of contextual variety in practice situations not only makes learning less context-dependent, but also involves participants in deeper and more

elaborative processing, thus leading to greater retention performance, as well as better transfer to novel or different contexts.

Relational Processing Theory

In recent years, the contextual interference effect has generally been explained by two main classes of theoretical mechanisms. The first mechanism emphasizes the structure, organization, and interconnectivity of long-term memory representations developed during acquisition. This mechanism has been associated with *interitem* or *relational* processing. The key idea is that random practice of to-be-learned information promotes relational, interitem processing in working memory on each trial during acquisition; that is, participants are comparing and contrasting the different items to be learned. During blocked practice, however, only one item is to be remembered (or one rule instantiated) on each trial, so there is neither motivation nor opportunity for relational processing. As with the contextual variability theories of spacing effects, learners in a random schedule develop a rich set of distinctive retrieval cues. This type of mechanism has been shown to play a role in distinguishing and choosing among items in a set, or among different procedural rules (Lundy, Carlson, & Paquiot, 1995).

The relational processing view is consistent with Battig's theories about similarity-induced schemas for maximizing learning during acquisition. Both of these views focus on the organizational aspect of representations during learning in a random schedule, and stress the importance of comparison and discrimination between rules or items to-be-learned. A study reported by Zimny (1981; cited in Shea & Zimny, 1983 & 1988) revealed that verbal reports from participants in a random schedule of learning differed substantially from those in a blocked acquisition schedule. Participants were to learn various arm movement patterns, similar to the tasks used by Shea and Morgan

(1979). Behavioral results demonstrated a significant contextual interference effect, and concurrent verbal reports mapped onto these results, revealing qualitative differences in intertask processing. Zimny found that participants in a random schedule tended to make more comparisons and evaluations of the to-be-learned patterns between practice trials, which is consistent with the relational processing view.

Intraitem Processing Theory

Lee and Magill (1983) offered a different explanation of the contextual interference effect, which can be thought of as a *reconstruction* (or *retrieval practice)* viewpoint. During blocked practice, the necessary item or rule can be held in working memory across trials. Under a random practice schedule (high contextual interference), however, learners are forced to retrieve the item or reconstruct the appropriate procedure from memory on each trial. This leads to superior long-term retention and transfer performance since participants get more practice, in a sense, in the skill needed for long-term retention: retrieving the material from long-term memory after a period of inactivity.

This second theoretical mechanism proposed to explain contextual interference effects can be thought of as an *intraitem* processing mechanism that emphasizes the efficiency of processes in working memory within each practice trial. This view therefore emphasizes the efficiency in accessing various skills or procedures rather than comparing or choosing among them (Schneider, Healy, Ericsson & Bourne, 1995; Lee & Magill 1983).

The retrieval practice view is also consistent with the concept of *procedural reinstatement* (Healy, Fendrich, & Proctor, 1990), which holds that retention is enhanced if during acquisition learners engage in the same procedures (e.g., rule retrieval) that will be required during the testing phase. This seems to be a more specific and more recent

reincarnation of *transfer-appropriate processing* (Morris, Bransford, & Franks, 1977), where practice at retrieving in acquisition is appropriate for retrieving the same information later at test (whether in retention or transfer situations).

Bjork (1975, 1988) has also suggested that retrieval practice is a very important factor in these learning paradigms in that it gives the learner specific practice at the required process of retrieving items from long-term memory. As long as these same processes of retrieving items or rules are needed for retention, then the added difficulty of repeated retrieval practice at acquisition can actually serve to enhance retention performance. These ideas are consistent with both procedural reinstatement and transfer-appropriate processing, as well as with the intraitem view of contextual interference.

Many have suggested that these two mechanisms are not necessarily mutually exclusive, and that both relational and intraitem processing might be taking place during acquisition in high-interference conditions. Lundy, Carlson, & Paquiot (1995) have suggested that relational, interitem processing might prove to be most beneficial when many procedures or operators might apply at each step. However, when only a few procedures are available, intraitem processing can lead to efficient and fluent accessibility of these rules in working memory (Lundy, Carlson, & Paquiot, 1995; Carlson & Yaure, 1990). Battig's (1979) early work also seems to suggest that participants may benefit from relational processing when the items to-be-learned are highly similar.

Domains of Contextual Interference

Throughout the last decade, contextual interference has been investigated in numerous learning domains, including motor, verbal and most recently, cognitive skill learning. The next three sections elaborate some of the research in these domains.

Motor learning

The majority of recent research investigating the effects of practice schedules on contextual interference has been in the motor learning domain (for a review, see Magill & Hall, 1990; Catalano & Kleiner, 1984; Lee & Magill, 1983; Shea & Morgan, 1979; Kerr & Booth, 1978). One such study examined the bean-bag-tossing skills of children (Kerr & Booth, 1978). Young participants either practiced throwing bean bags at a target that was 3 feet away, or had varied practice with targets 2 feet and 4 feet away. They were then tested with a target that was 3 feet away. Those that had the varied practice (2 and 4-foot distances) performed better on the test target (3-foot distance), even though the constant practice group had specific practice with the test distance. These results suggest that learning how to adapt and adjust to the various distances was more important than the specific experience with the test distance, consistent with the interitem, relational explanation of contextual interference.

One of the first reports of contextual interference in learning motor skills using random and blocked practice was reported by Shea and Morgan (1979). Participants were required to learn multiple-segment arm movements in response to different stimulus lights. Participants learned the various arm movements in either a blocked or random acquisition schedule. In the blocked condition, participants practiced all trials of one arm movement pattern before moving on to the next movement pattern. In the random schedule, the trials for each pattern were randomly distributed among all practice trials for all patterns.

During acquisition, their results supported Battig's (1972, 1979) predictions for contextual interference, with the blocked group performing more quickly and with fewer errors than the random group. Retention tests revealed the opposite findings; the random

group now outperformed the blocked group in both speed and accuracy. After the retention tests, participants attempted two transfer tasks involving new, but similar movement patterns. Again consistent with Battig's predictions, the random group outperformed the blocked group on both transfer tasks. Shea and Morgan's (1979) experiment was one of the first studies to demonstrate the contextual interference effect in motor learning. This study also revealed that higher levels of interference during learning not only increased long-term retention, but also increased transfer performance to novel tasks.

Verbal learning

The effects of blocked versus random practice on contextual interference have been extended in a few cases to the verbal learning domain (Mannes & Kintsch, 1987; Nitsch, 1977). Additionally, Battig's (1972) own early work on intratask interference involved paired-associate learning. Participants were to learn 12 different paired-associate lists, and interference was manipulated during learning by varying block size (1, 2, 4, 6, and 12). The groups were organized according to the schedule of presentation of the stimulus alone, and the stimulus-response pairs. For example, the group with the least amount of interference (group 12) was presented with all stimuli alone for all 12 lists in order, and then all the stimulus-response pairs for all lists. On the other hand, group 1 was presented with one stimulus, followed by the stimulus-response pair for each list. During acquisition, the extreme blocked schedule (group 12) had the best performance, with groups 1 and 2 performing least accurately. Tests of free recall, however, showed that groups 1 and 2 performed the best, whereas group 12 performed the worst. These results were consistent with Battig's predictions of the benefits of high contextual interference during learning.

Cognitive skills

Although there have been numerous studies of contextual interference in the motor and verbal learning literature, there has been only limited research on contextual interference in the learning of higher level cognitive skills.

Schneider, Healy, Ericsson, and Bourne (1995) have demonstrated significant contextual interference effects on the acquisition and retention of logical rules. Participants were trained to use Boolean logical rules ('AND,' 'OR,' 'NAND,' 'NOR') using various practice schedules (blocked, serial, and random). The serial condition was included to determine the effect of predictability of the to-be-learned rules on the contextual interference effect. Since in the serial condition the learning sequence/presentation pattern is fixed, participants can prepare for the following trial by retrieving the next item or rule into working memory before the trial begins (called "preloading"), therefore speeding their reaction time. Schneider et al. found that the blocked group yielded the shortest response times during acquisition, with the random group showing the longest response times. This trend was reversed for retention performance; blocked practice led to inferior performance on both immediate and delayed posttests, whereas the random group yielded superior performance on both posttests. The serial group's performance fell in between the blocked and random on both acquisition and retention. These results suggest that both unpredictability and the need to retrieve the rule from memory on each trial contributed to the contextual interference effect.

Carlson and Yaure (1990) also investigated contextual interference effects in the learning of cognitive procedural skills and their transfer to subsequent problem solving. Participants practiced Boolean logical rules under a blocked or random schedule and

were then tested on "equation-chaining" problems, where several logical rules must be combined. Though their acquisition was slower, participants who had practiced under a random schedule solved the chaining problems more quickly, and this difference was greatest for the most difficult problems.

Carlson and Yaure interpreted their results as evidence for the importance of intraitem processing in producing the contextual interference effects, where on each trial in random practice participants must reconstruct the item to-be-remembered. According to Carlson and Yaure, this is analogous to loading a cognitive procedure into working memory on each trial. Retrieval or reconstruction practice can increase fluency in accessing and using component skills, and the overall efficiency of related processes in working memory. As mentioned above, the random group solved the chaining problems more quickly, and this difference was greatest for the most difficult problems. These difficult problems required more logical rules to be applied, and therefore subjects had to maintain and manipulate larger amounts of information in working memory. They suggest that these results are due to reductions in the working memory demands of performing the component skills, which resulted from random practice retrieving the logical rules during acquisition (Carlson & Yaure, 1990).

The Present Investigation

One purpose of the present set of experiments is to more closely integrate contextual interference effects with those of the distribution of practice. The preceding review makes it clear that in both cases, activity that intervenes between occurrences of the critical material or tasks retards acquisition, but facilitates transfer and long-term retention. Also, the alternative explanations for these effects are quite similar, contrasting intraitem processes (retrieval practice, deficient processing) and interitem processes

(contextual variability, relational processing). In the typical spaced-practice study, the intervening activity is generally unrelated to the critical items or task, while in the typical contextual-interference study, the intervening activity is often closely related to the critical items or task.

There is evidence, however, that the type of activity that intervenes between trials in either a contextual interference or spacing effect study important in understanding variations in long-term retention. Proctor (1980, Exp. 1) investigated the difficulty of the intervening task in a spacing effect paradigm and found that the usual superior retention for spaced repetitions was eliminated, at least for a frequency judgment measure of memory, with a challenging intervening task of classification. In contrast, an easier task of left-right comparison did not reduce the spacing advantage in retention.

Other studies have shown that a blocked schedule with an intervening task between each trial (considered "blocked" in terms of the main task) can lead to transfer performance comparable to that following a random practice training schedule. Carlson and Yaure (1990, Exp. 3) attempted to enhance intratask processing by incorporating an intervening task into a blocked schedule in their Boolean logic learning task. They examined transfer performance in subsequent problem solving tasks from "blocked" practice in which the intervening tasks varied in their processing requirements. Since Baddeley's (1994, Baddeley & Hitch, 1974) research on working memory suggests storage and processing capacities of working memory are separable, two active-processing tasks (a same/different task and a math verification task) and two storage tasks (short-term and long-term memory tasks) were utilized. Participants in the same/different and math task conditions solved the transfer problems faster than those in the storage task conditions, very similar to random performance (as seen in their Experiment 1).

However, this transfer benefit was primarily for the math verification task, which involved a substantial working memory load. Carlson and Yaure concluded that the active-processing tasks "cleared out" working memory and forced participants to reload the rules on each trial, much like the demands of a random acquisition schedule.

In Experiment 1, I attempt to validate Carlson and Yaure's (1990) claims that the contextual interference effect for this type of cognitive skill is due primarily to the intraitem processing demands of random versus blocked schedules, using a more complex task that has greater potential for interitem, relational processing (see below).

An additional purpose of Experiment 1 was to explore how long-term retention of this complex learning task was influenced by the contextual interference manipulations. Carlson and Yaure (1990) focused on transfer performance on an immediate problem-solving task, and did not have any immediate or delayed tests of retention of the individual rules.

A third purpose of the first experiment was to develop a learning task that could be used to more directly test the relational-processing hypothesis. There are several potential problems that arise with the use of the common Boolean rules used by Schneider, et al. (1995) and Carlson and Yaure (1990). First, the Boolean symbols used by Carlson and Yaure (1990) and Schneider et al. (1995) are also used in symbolic logic and computer programming, but their use was in some cases inconsistent with conventional use in those fields. Participants are also likely to have differing degrees of past experience with Boolean operations and concepts. New symbolic mathematical rules are introduced in this study to alleviate these problems. Thus, the generality of Carlson and Yaure's (1990) findings will be tested with a substantially different set of rules and materials.

In Experiment 2, which was implemented concurrently with Experiment 1, the stimulus materials were modified to afford greater opportunity for relational, interitem processing in the acquisition of these cognitive operations, and by comparison to performance in Experiment 1, directly test its contribution to the contextual interference effect. It is claimed that relational processing allows the learner to compare and contrast to-be-learned items or rules, which leads to a rich set of distinctive retrieval cues. This type of processing does not occur during blocked acquisition schedules, which deal with one rule or item at a time, even if an intervening task causes the clearing out of working memory. Some researchers advocate that this relational, interitem processing across trials is the primary factor that serves to enhance transfer and retention performance in random (high-interference) practice schedules. (Wright, 1991; Shea & Zimny, 1988)

Some support has been found for the intraitem processing/retrieval practice views (Carlson and Yaure, 1990; Schneider et al. 1995), but there has been little direct support for the role of relational, interitem processing in contextual interference. This may be due to the design of the tasks themselves, which may not afford comparative or contrastive encoding during acquisition. The Boolean logic rules utilized by Carlson and Yaure (1990) and Schneider et al. (1995), for example, provide no obvious opportunity for relational processing. Participants might be able to memorize the Boolean rules and their respective responses in one step (via the truth table), thus making the task very simplistic. In Experiment 2, interitem relations were specifically added to the symbols and rules of the main task, and their impact on contextual interference examined.

EXPERIMENT ONE

As described above, it has been argued that any reasonably challenging intervening task might serve to clear out working memory so that rules or procedures must be retrieved from memory and 'reloaded' into working memory on the next trial, thus fostering intraitem processing and leading to superior transfer and retention performance. Evidence for this comes from the superior transfer performance for a blocked practice schedule when a secondary task intervenes between each trial (Carlson & Yaure, 1990).

Experiment 1 was designed to manipulate such intraitem processing through the use of a blocked-plus-intervening task practice schedule, and to examine its influence on contextual interference effects with new symbolic mathematical rules. Examples of the novel symbolic mathematical rules that are utilized in this experiment are shown in Figure 1. As with the previously-used Boolean logic rules (Schneider et al., 1995; Carlson & Yaure, 1990), the notation format remains relational, with symbols marking the type of operations to be performed on a set of values. The symbols are drawn from the written language Kanji, a Japanese system of writing that utilizes characters adapted from Chinese writing. The symbols previously used to mark Boolean rules (&, #, ^, *) have been substituted by Kanji characters linked to more complex mathematical sequence rules. As previously mentioned, the original Boolean symbols used in the main logical task were inconsistent with conventional use, and past experience with Boolean logic was

not controlled. The use of unfamiliar Kanji symbols linked with more complex rules was intended to solve these problems.

Another criticism of the Boolean task is the fact that there are only two response alternatives (0 or 1), and a corresponding guessing rate of 50%. By utilizing mathematical rather than logical rules and decimal rather than binary elements, the new task provides many more response alternatives. This wider range of responses provides a potentially more sensitive measure of learning and memory.

In Experiment 1, unique Kanji-like symbols represent different mathematical sequence rules to be applied to the three numbers in parentheses. For example, the symbol on the right in Figure 1 represents this sequence: [(B + C) - A]. In this instance, the correct response would be '2' [(5 + 0) - 3]. Participants are presented with six different rules to be learned, each with its own unique Kanji symbol. This also addresses another problem regarding the simplicity of the original Boolean rules. These more difficult symbolic mathematical operations require several arithmetic steps as well as attention to grouping and order of operations.

To summarize, the new symbolic math task requires identification of the Kanji symbol, retrieval of the symbol's general rule pattern (its "meaning"), and the implementation of the specific mathematical rule to the numbers in parentheses.

The central feature of this set of experiments is the use of three different kinds of practice schedules during rule acquisition. The random practice group is given repeated practice with six symbolic rules presented in random order. The blocked practice group practices each rule repeatedly in blocks. The blocked-plus-intervening-task (blocked IT) practice group also is given blocked practice, but has a brief intervening task between each trial within a block, which is intended to displace the primary task and materials

from working memory between trials. This forces the participants to retrieve the to-be-learned rule on each trial (intratask processing), but does not provide the contrastive presentation of rules within blocks that would facilitate relational (intertask) processing.

The intervening task in this paradigm is a math/verbal verification task adapted from Lundy et al. (1995) and Carlson and Yaure (1990), as shown in Figure 2. In this task, participants verify the answer to a three-digit addition problem. Carlson and Yaure and Lundy et al. maintain that the processing demands of this task require calculation procedures (or rules) that are similar to those needed for the Boolean logic problems. Because the Kanji symbols in this paradigm correspond to mathematical rules, it is assumed that the overlap of procedures in the main and intervening tasks should serve to clear out working memory in the blocked IT condition and offer the opportunity for retrieval practice.

We expect to replicate the contextual interference effect with these symbolic mathematical rules, and extend the results to long-term retention. Further, the blocked practice group should outperform all groups during acquisition (least amount of errors and fastest reaction times), yet show increased latency and errors in retention performance. Random practice should result in worse performance than blocked practice during acquisition, but superior subsequent long-term retention (less errors and shorter response time). If, with these materials and task, the contextual interference effect is due wholly to an increase in intraitem processing in the random practice condition, then the blocked IT performance should be similar to the random practice group during retention, since in both conditions intratask processing would be enhanced by the need for retrieval practice. By the nature of the unique symbols and rules in Experiment 1, there should be little opportunity for relational (intertask) processing (in contrast to Experiment 2).

Method

Participants

Forty-five undergraduates (7 males, 38 females) at the University of Florida participated in this experiment. Additionally, six graduate students volunteered as pilot testers. Participants were randomly assigned to the three experimental groups. They received credit towards an introductory psychology course requirement, or extra credit points in a cognitive psychology class, if they participated fully and returned for the retention test. Participants who did not return for the retention test 48 hours later were given two experimental credits for participating during acquisition, but then were excluded from the results. This left 42 participants (6 males, 36 females), with 14 in each acquisition condition. Motivation to return for the second part of the experiment was provided in the form of a monetary reward ($50) for the best few participants. As many as eight participants were tested at the same time.

Materials and Apparatus

The acquisition and retention tests were administered on IBM-compatible computer workstations and the experiment was programmed using the E-Prime 4.0 platform (Schneider, 1999). Examples of the Kanji symbols are shown in Figure 1. The full set of symbols and their corresponding rules are presented in Appendix A. The screen size was approximately 24 cm by 32 cm, and the rules were displayed in the middle of the screen. Participants indicated their responses using the keyboard. The letters 'Q' through 'P' on the keyboard were marked as the numbers '11' through '20' to allow for one key-press responding and more accurate response time measurement. An example of the intervening task (for the blocked IT condition only) is shown in Figure 2. Participants

responded to the intervening task by either pressing 'T' (true) or 'F' (false), which were marked on the keyboard.

Design

The design for the acquisition phase was a 3 x 6 mixed factorial. Acquisition condition was varied between subjects (random, blocked, blocked IT) and practice block was varied within subject. The design for the retention phase was a 3 x 3 mixed factorial, with the acquisition condition manipulation carried forward (between subjects), and block manipulated within subjects.

Procedure

Acquisition. The participants learned the six symbolic mathematical rules in one of three acquisition schedules: random, blocked, and blocked with an intervening task (IT). Participants in all groups practiced the rules for six blocks of 30 trials (180 trials). The random group learned the six symbolic rules in random order, with five trials each per block. In the blocked and blocked IT groups, each block included 30 trials with a single rule. For blocked groups, the order in which rules appeared was counterbalanced.

After a brief introduction and an informed consent procedure, the experimenter described the acquisition task. Participants also had three display screens of instructions, along with an example, which were self-paced. They were told to ask questions before they began if they did not understand the task. When they were ready, they pressed the space bar to begin the experiment. A Kanji symbol was presented on the left side of the screen, with six choices of sequential rules labeled 1 through 6 listed on the right side of the screen. Participants chose the correct rule by pressing the number of the rule (1-6), and the computer displayed feedback as to their accuracy. If they were incorrect, they were told to try again via a red error screen that was presented for four seconds. Then, the

same symbol and six rules were presented again. If they were correct, they were shown the correct mathematical rule sequence again for four seconds and were told to apply this rule to the following numbers in parentheses. This long presentation of four seconds was utilized as a motivation aid, as participants increased their time in the task for every error. Post-hoc comments by the participants suggested that they tried to perform well so they wouldn't see and have to wait through the presentation of the dreaded "red screen". Four seconds was also sufficient time for the participants to see and understand the correct rule before having to apply it.

After participants chose the correct symbol-rule pairing, the Kanji symbol was shown again with a set of three numbers in parentheses (see Figure 1), and participants were to apply the rule to these numbers. They responded with the correct solution to the problem via the keyboard. Accuracy and latency feedback was given for every application of the rule, and was presented on the screen for 1.5 seconds. On successive trials, the order of the six listed math rules was randomized so that participants could not just memorize the number of the rule. This randomization also forced participants to search through the six potential rules for the correct rule on each trial, even in the blocked schedule, thus minimizing 'searching' differences in the three schedules.

For the blocked IT condition only, two math verification problems intervened between every trial during acquisition. A three-digit addition problem, plus a solution was presented on the screen, and participants had to respond by pressing the letter "T" if it was a true mathematical statement or "F" if it was a false statement. There were two math verification problems per trial, which added up to 360 verification problems total. Participants were given accuracy feedback for 1.5 seconds on every trial of the intervening task.

After every block of 30 trials, participants were given the opportunity to rest their eyes or stretch, so that they did not take breaks during rule retrieval or problem solution. The acquisition phase took about 45 minutes to an hour for the random and blocked conditions, with the blocked IT groups taking an hour to an hour and twenty minutes.

Retention. Participants were required to return after 48 hours to complete a delayed retention test of the learned material. They were not initially informed of the nature of this second day of testing so that they would not deliberately rehearse the information over the retention period. The retention test consisted of three blocks of 30 trials, presented in random order. The procedure was exactly the same as the acquisition phase, with the exception of the random presentation for all three acquisition-conditions. Participants had three screens of instructions to refamiliarize themselves with the task if they wished. The retention phase took about 30 minutes.

The main dependent variables for both acquisition and retention included: latency to choose the correct rule (in seconds), accuracy in picking the correct rule (number of errors made), and latency in application of the rule (in seconds). The latency and accuracy of the intervening task were also recorded, as were the specific errors (choice of rule) made during rule retrieval. For all conditions, participants were instructed to respond as quickly as possible while maintaining a high level of accuracy.

Results and Discussion

Results are presented for three dependent variables for both acquisition and retention: 1) mean reaction time to select the correct rule, 2) mean latency in applying the rule, and 3) the mean number of errors during rule selection. Data from participants who did not return for the retention session were excluded from the acquisition results.

Acquisition

Rule selection. Participants in the random group responded significantly slower in both choice and application of the correct rule across all blocks of acquisition. Figure 3 displays the mean latency for choosing the correct rule across practice blocks for each of the three acquisition schedules. The random group took nearly 3 times longer to select the correct rule ($\underline{M}$ = 14.4 s) than the blocked group ($\underline{M}$ = 5.8 s) for the early practice blocks. This difference diminished across practice blocks, yet the random practice group still responded more slowly than blocked even in the last practice block ($\underline{M}$ = 4.5 s; $\underline{M}$ = 3.4 s, respectively). The improvement in speed for the random acquisition group followed a power function, revealing a faster rate of improvement than either of the blocked conditions. However, the random group never achieved latencies as fast as the blocked groups.

Unexpectedly, the blocked IT group's performance was almost identical to that of the blocked group (see Figure 3). The largest difference between the two blocked groups was in block 1, where the mean for the blocked group was 5.8 s as opposed to the blocked IT group's mean of 4.9 s. This difference was not significant, however, and by the second block the difference between the two groups stabilized to less than 300 ms. By the last block, the mean times for the blocked and blocked IT groups were 3.44 s and 3.40 s, respectively.

Analyses of variance (ANOVAs) were performed on all data using an alpha level of .05, using a sphericity correction by the Huynh-Feldt (H-F) statistic. However, uncorrected degrees of freedom (df) will be presented throughout this paper for clarity. A 6 x 3 mixed ANOVA on these data show that there was a significant overall main effect of practice schedule on time to choose the correct rule, $\underline{F}(2, 39) = 42.95$, $\underline{p} < .001$. There

was also a significant main effect of practice block, $F(5, 195) = 62.98$, $p < .001$, and a significant interaction between acquisition schedule and block, $F(10, 195) = 23.29$, $p < .001$. The random group improved more rapidly across blocks than the blocked groups, as can be seen in Figure 3. Specific pair-wise comparisons related to the hypotheses of the study were also conducted, with an adjusted α-level of .01 used for all t-tests. Due to the nature of the different practice schedules, unequal variances were assumed and thus, Dunnett's pair-wise comparisons (T3) were conducted. Dunnett's t-tests confirmed that the random group was significantly slower than both the blocked and blocked IT conditions and that there were no significant differences between the two blocked groups.

Rule application. Interestingly, a significant difference in response time was found in rule application as well, which is illustrated in Figure 4. The random group applied the rules more slowly ($M = 5.4$ s) than the blocked group ($M = 4.0$ s) in the early practice blocks, as well as in the last practice block ($M = 3.8$ s; $M = 3.1$ s, respectively). The blocked IT group applied the rules slightly faster than the blocked group, with a mean of 3.8 s in the first block, and 2.9 s in the last, but this was not significantly different than the blocked group. An ANOVA confirmed that during acquisition, there was an overall main effect of practice schedule on time to apply the rule, $F(2, 39) = 7.85$, $p = .001$. There was also a main effect of block, $F(5, 195) = 35.06$, $p < .001$, and a significant interaction between block and acquisition schedule, $F(10, 195) = 4.33$, $p = .001$. The random group improved at applying the rule at a quicker rate than did the blocked or blocked IT groups. Dunnett's T3 tests again confirmed that the random group was significantly slower than both the blocked and blocked IT conditions and that there were no significant differences between the two blocked groups.

Errors. As expected, participants also made significantly more errors across all acquisition blocks in the random practice schedule, as shown in Figure 5. In the first block, the random group averaged 54.3 errors to the blocked group's 5.4 errors. By the last block, this difference had decreased, but random was still less accurate (M = 6 errors) than blocked (M = 1.7 errors). Blocked IT performance was again similar to the blocked group's performance, with a mean of 5.1 errors in the first block, and 2.2 errors in the final block. There was a significant main effect of acquisition schedule, $F(2, 39) = 27.79$, of practice block, $F(5, 195) = 64.07$, and a significant interaction between the two factors, $F(10, 195) = 45.64$, all p's < .001. Again, Dunnett's t-tests confirmed that the random group made significantly more errors than both the blocked conditions and that there were no significant differences between the blocked and blocked IT groups.

Retention

Rule selection. A significant contextual interference effect was observed in latency for both choosing and applying the rule, as well as for accuracy. Figure 6 shows the mean latency for choosing the correct rule across the three retention blocks in all three acquisition conditions. In contrast to acquisition performance, the random group performed significantly faster than the blocked group across all three blocks. In the first retention block, the random group averaged 5.2 s to choose the correct rule, whereas the blocked group averaged 12.9 s. This difference lessened in the third block, but random practice was still much faster (M = 3.7 s) than blocked (M = 7.8 s). The random group also outperformed the blocked IT group, as participants in the blocked IT group averaged 13.1 s in the first block, and 6.0 s in the last block. An ANOVA confirmed that there was a significant main effect of practice schedule for the retention test, $F(2, 39) = 24.19$, p < .001. There was also a main effect of block, $F(2, 78) = 62.26$, p < .001, and a significant

interaction between block and acquisition schedule, $F(4, 78) = 8.62$, $p < .001$. With an adjusted alpha value of .01, Dunnett's t-tests confirmed that the random group performed significantly faster across all three blocks than both the blocked and blocked IT conditions and that there were no significant differences between the two blocked groups.

Rule application. Figure 7 shows the mean latency for rule application across retention blocks in all three acquisition schedules. Though slower at acquisition, the random group was significantly faster ($M = 3.3$ s) at applying the rule across all retention blocks than the blocked group ($M = 4.6$ s); confirmed in the significant main effect of practice schedule, $F(2, 39) = 6.89$, $p = .003$. There was no main effect of block. Dunnett's pair-wise comparisons revealed that the blocked group was significantly slower than both random and blocked IT, but interestingly, the random and blocked IT conditions were not significantly different from one another.

Errors. Figure 8 shows the mean number of errors across blocks for the three acquisition conditions. In contrast to acquisition performance, the random group performed with the greatest accuracy across all blocks in retention. In the first retention block, the random group averaged 5.8 errors to the blocked group's 50.1 errors and the blocked IT group's 45.3 errors. By the last block, this difference lessened to random averaging 2.4 errors with blocked and blocked IT averaging 14.9 and 12.3 errors, respectively. An analysis of variance revealed this to be a significant difference, $F(2, 39) = 20.66$, $p < .001$. There was also a main effect of block, $F(2, 78) = 79.72$, $p < .001$, and a significant interaction between block and acquisition condition, $F(4, 78) = 15.00$, $p < .001$. Once again, Dunnett's post-hoc comparisons revealed that the random group significantly outperformed the two blocked groups and blocked IT performance was not significantly different from blocked.

The results from Experiment 1 revealed a strong contextual interference effect in learning novel sequential mathematical rules paired with Japanese symbols. The random group was significantly slower and made more errors than the blocked groups during acquisition. As predicted, this trend was reversed in retention, with the random group performing more quickly than the blocked groups, and making very few errors (all p's < .001). These results are consistent with Battig's (1972, 1979) original predictions, and with the large amount of literature on contextual interference effects in motor and verbal learning, extending these findings to a more complex cognitive task.

An interesting finding was that this significant contextual interference effect was also evident in the application of the rules. After choosing the correct symbol-rule pairing, participants then applied that rule to a set of numbers in parentheses. The random group applied the rules more slowly during acquisition, yet during retention they performed much more rapidly than the blocked groups. Even when presented with the correct rule to apply, the presence of six other potential rules in memory (in the random schedule) may have created conditions of interference, leading to slower application times in acquisition. Consequently, this heightened interference during acquisition led to faster application times in retention. The presence of contextual interference effects in the application of rules (a different kind of cognitive/procedural "skill") is a new and interesting finding that broadens the scope of these interference effects. Deeper investigation is needed to determine how generalizable these results are to other learning situations.

However, Carlson and Yaure's (1990) claim that random-like intraitem processing can be produced with an intervening task paradigm was not supported. In their study, a blocked IT schedule produced transfer performance similar to random performance. They

attributed this to the need for rule retrieval in both the blocked IT and random conditions. However, closer inspection of their acquisition data (see Figures 4 and 9 in Carlson and Yaure, 1990) reveals that the blocked IT group performed closer to the blocked than the random group during learning, suggesting that the retrieval demands and workload of a random schedule were not replicated with the addition of an intervening task to a blocked schedule.

It was assumed that the intervening task cleared out working memory and forced the participants to retrieve the rules from long-term memory, thus making blocked performance similar to random performance. However, in a blocked practice schedule, there is only one rule that needs to be retrieved, so it is possible that the relevant procedure or rule stays 'activated' somehow in long-term memory even during the intervening task, and thus remains easily accessible. This might be the case in spacing effect studies (where the intervening activities are usually not closely monitored, or systematically manipulated) as well as in contextual interference studies. By analogy, the situation may be like the very first trial in Keppel and Underwood's (1962) study of short-term memory. They demonstrated that, in the absence of proactive interference from prior trials, the three-consonant trigram presented on the first trial was remembered perfectly over intervals of up to 20 seconds of a difficult distractor task (counting backwards by three's). In the present blocked-practice conditions, the critical information remains the same over all the trials within a block, whether massed or spaced, which would tend to further reinforce its accessibility across trials of that block.

In the present study, it therefore remains unclear whether the random group's advantage was due to intraitem or relational processing. The results are clearly consistent with an intraitem processing view, if one accepts the claim that the blocked IT schedule

did not recreate the processing demands of a random schedule during learning. We cannot, however, rule out the contribution of relational processing to the contextual interference effect that was observed, even though the materials in Experiment 1 were designed to minimize such processing.

Investigations into relational processing have been few, perhaps due to the difficulty in developing tasks that could specifically test this hypothesis (Adams, 1983). For example, recent studies of contextual interference in cognitive skill learning (Schneider et al., 1995; Carlson & Yaure, 1990) have utilized Boolean logical rules. Boolean rules as implemented in these studies do not afford the opportunity for much comparative or contrastive encoding during acquisition, as they can be memorized in one step, or via truth tables.

As previously mentioned, Shea and Zimny (1983, 1988) advocate the idea that random acquisition promotes relational processing activities across practice trials. Their verbal report data revealed qualitative differences between blocked and random modes of processing. According to this theory, a random schedule offers an additional mode of processing (relational, interitem processing) that is not available in a blocked schedule. It is this additional opportunity for comparing and contrasting that is a key factor contributing to heightened retention performance of random, high-interference groups.

More recently, Wright (1991) aimed to investigate the roles of inter- and intratask processing in the learning of a motor skill by manipulating the type of processing in which participants were engaged during acquisition. Participants learned three different barrier knock-down tasks in a blocked schedule. Opportunities were provided between each trial to engage in intertask processing, intratask processing, or no additional processing. In the intertask processing schedule, participants were shown diagrams of one

of the other to-be-learned movement patterns, and were asked to identify similarities. The intratask processing group was asked to verbalize the movement pattern that was just practiced. Wright found that the intertask-comparison group performed significantly faster (and with fewer errors) at retention than did the other conditions.

Wright's (1991) results are consistent with the views of Shea and Zimny (1983, 1988) and offer some support that engaging in intertask processing between trials while experiencing blocked practice facilitates motor retention performance. Experiment 2 similarly attempted to manipulate relational processing, not by instructions, but by providing an organizational structure in the materials that linked similarities of the Kanji symbols to similarities of the mathematical rules.

住(3, 4, 4)　員(3, 5, 0)

Figure 1. Japanese Kanji symbols

2 4 5
+ 3 7 3
5 1 8

Figure 2. Example of the math/verbal verification task (intervening task) for the blocked IT acquisition condition

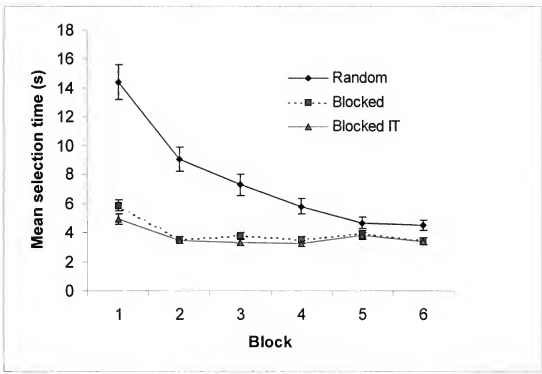

Figure 3. Mean time (in seconds, +/- SE) to select the correct rule across practice blocks for each of the three acquisition conditions.

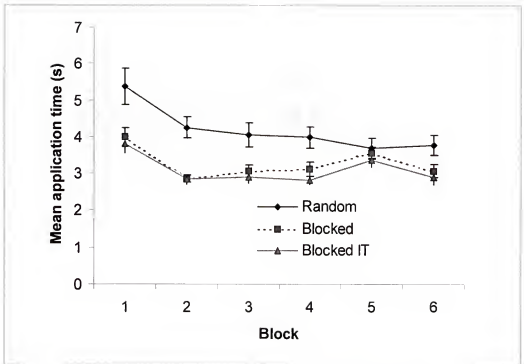

Figure 4. Mean rule application time (in seconds, +/- SE) across practice blocks for the three acquisition schedules

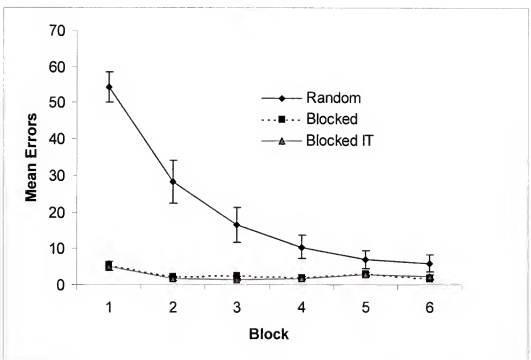

Figure 5. Mean number of errors across practice blocks in each of the three acquisition conditions

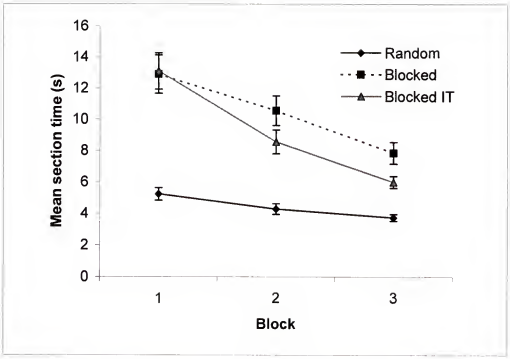

Figure 6. Mean time (in seconds, +/- SE) to select the correct rule across retention blocks for each of the three acquisition conditions

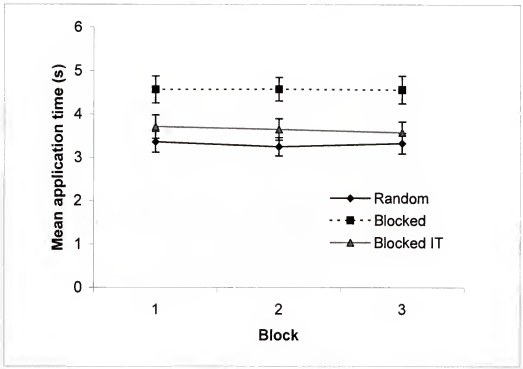

Figure 7. Mean rule application time (in seconds, +/- SE) across retention blocks for the three acquisition schedules

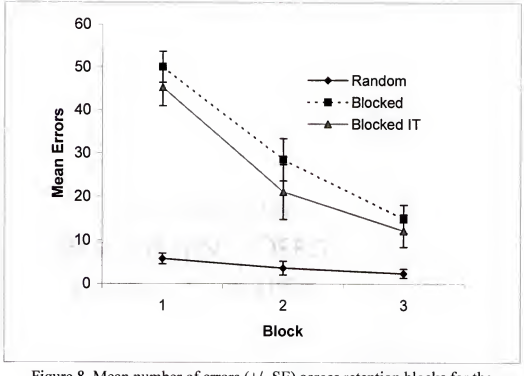

Figure 8. Mean number of errors (+/- SE) across retention blocks for the three acquisition conditions

EXPERIMENT TWO

The use of novel Kanji-like characters provides the opportunity to represent relations between the rule symbols that correspond to relations in the mathematical rules. Kanji-like characters that have embedded common elements are included in Experiment 2. In Japanese Kanji, these common elements are called *phonological markers*; Kanji characters with the same marker are pronounced the same (despite the conventional view that Kanji is a fully nonphonetic, holistic script). Examples of symbols with common elements or 'markers' are shown in Figure 9.

In Experiment 1, the Kanji characters were unique and unrelated; in Experiment 2, the Kanji symbols include these common elements that correspond to similarities in the mathematical rules. Kanji characters with similar embedded elements will represent similar mathematical sequence rules. Examples of related symbolic rules and symbols in this condition are shown in Figure 10.

Experiment 2 includes the same three practice conditions as Experiment 1 (random, blocked, blocked IT). The random practice schedule should allow the participants maximal potential to compare and contrast between the different rules (and their corresponding symbols), providing a greater opportunity to build up some relational structure than when no set-wide organization is present. For example, the first symbol in Figure 10 represents this sequence: [(B + C) * A)] and the related symbol below it represents this similar sequence: [(B + C) - A]. Comparing between rules and symbols, participants can link the small box figure in the center of the Kanji character to the

sequence [(B operator C) operator A]. Just as participants can use the common element in the Kanji to retrieve the abstract rule pattern, they can contrast the differences in the symbols to discriminate which sequence of operators to apply.

It is this extra relational processing that we expect will lead to a greater overall contextual interference effect for Experiment 2. The opportunity to compare and contrast these rules on a trial-by-trial basis is only afforded by random acquisition, and this in turn should lead to a greater advantage for random over blocked practice in subsequent retention performance than that found in Experiment 1. Conversely, the heightened processing requirements and extra cognitive work presented by the increased similarity among symbols during acquisition should lead to slower learning for the related symbols compared to that of the unique symbols in Experiment 1.

A random schedule should allow for the grouping of related elements in memory that is not available when learning one rule at a time (as in the two blocked conditions). Therefore, it is also hypothesized that the extra relational processing afforded by the random practice condition should lead to superior retention performance over both the blocked and the blocked IT task conditions. The blocked IT condition is again included due to the fact that Experiments 1 and 2 were run concurrently. Since we could not produce sufficient intraitem processing in an intervening task schedule in Experiment 1, it is assumed that blocked IT performance should again be very similar to that of the blocked condition.

Method

Participants

Forty-three undergraduates (5 males, 38 females) at the University of Florida participated in Experiment 2. Participants were randomly assigned to the three

experimental groups. They received credit towards an introductory psychology course requirement, or extra credit points in a cognitive psychology class, if they participated fully and returned for the retention test. Participants who did not return for the retention test 48 hours later were given two experimental credits for participating during acquisition, but then were excluded from the results. This left 42 participants (5 males, 37 females), with 14 in each acquisition condition. As in Experiment 1, motivation to return for the second part of the experiment was provided in the form of a monetary reward ($50) for the best few participants. As many as eight participants were tested at the same time.

Materials and Apparatus

The software and set-up was identical to that of Experiment 1. The symbols and rules were different, however, as related elements were built into the task. Examples of the related symbolic rule problems and sequential math rules are shown in Figure 10. The full set of related symbols and the corresponding rules can be found in Appendix B.

Design

The design for the acquisition phase was a 3 x 6 mixed factorial. Acquisition condition was varied between subjects (random, blocked, blocked IT) and practice block was varied within subject. The design for the retention phase was a 3 x 3 mixed factorial, with acquisition condition manipulated between subjects, and block manipulated within subjects.

Procedure

The procedure was identical to that of Experiment 1. The only difference was the use of the related symbol and rule set, as shown in Appendix B. Experiments 1 and 2 were run concurrently.

Results and Discussion

Results are presented for three dependent variables for both acquisition and retention: 1) mean reaction time to select the correct rule, 2) mean latency in applying the rule, and 3) the mean number of errors during rule selection. Data from participants who did not return for the retention session were excluded from the acquisition results.

Acquisition

Rule selection. Participants in the random group responded significantly slower in both choice and application of the correct rule across all blocks of acquisition. Figure 11 displays the mean latency for choosing the correct rule across practice blocks for all three acquisition schedules. The random group took more than 3 times longer to select the correct rule ($\underline{M}$ = 18.3 s, $\underline{SE}$ = 1.42 s) than the blocked group ($\underline{M}$ = 5.7 s, $\underline{SE}$ = 0.29 s) for the first practice block. This difference diminished across practice blocks, yet the random group still responded more slowly than blocked in the last practice block ($\underline{M}$ = 4.7 s, $\underline{SE}$ = 0.24 s; $\underline{M}$ = 3.4 s, $\underline{SE}$ = 0.15 s, respectively). Mirroring the performance in Experiment 1, the blocked IT group's performance was again almost identical to that of the blocked group (see Figure 11). The mean rule selection times for the blocked IT group were 4.8 s ($\underline{SE}$ = 0.36 s) and 3.4 s ($\underline{SE}$ = 0.21 s) for the first and last blocks, respectively. The improvement in speed for the random acquisition group again followed a power function, revealing a faster rate of improvement than either of the blocked conditions. However, as in Experiment 1, the random group never achieved latencies as fast as the blocked groups.

Analyses of variance (ANOVAs) were performed on all data using an alpha level of .05. The degrees of freedom (df) were again corrected for sphericity by the Huynh-Feldt (H-F) statistic, but the uncorrected df's will be presented for clarity. A 6 x 3 mixed

ANOVA on these data show that acquisition schedule had a significant effect on rule selection time, $F(2, 39) = 68.83$, $p < .001$. There was also a significant main effect of practice block, $F(5, 195) = 63.33$, $p <. 001$, and a significant interaction between acquisition schedule and block, $F(10, 195) = 32.90$, $p < .001$. The random group improved more rapidly across blocks than the blocked groups, as can be seen in Figure 11. Specific pair-wise comparisons related to the hypotheses of the study were again conducted on the data using an α-level of .01. As in Experiment 1, Dunnett's t-tests confirmed that the random group was significantly slower than both the blocked and blocked IT conditions and that there were no significant differences between the blocked and the blocked IT groups.

Rule application. The random group again applied the rules more slowly (M = 5.5 s, SE = 036 s) than both the blocked and blocked IT groups (M = 4.1 s, SE = 0.33 s, and M = 3.8 s, SE = 0.24 s) in the first practice block, as well as in the last practice block (M = 3.7 s SE = 0.37 s; M = 2.9 s, SE = 0.30 s; M = 3.5 s, SE = 0.24 s, respectively). An ANOVA confirmed this main effect of practice schedule during acquisition, $F(2, 39) = 7.46$, $p = .002$. There was also a main effect of block, $F(5, 195) = 25.82$, $p < .001$, and a significant interaction between block and acquisition schedule, $F(10, 195) = 4.72$, $p < .001$. As in Experiment 1, the random group improved in applying the rule at a quicker rate than did the blocked or blocked IT groups. Dunnett's comparisons confirmed that the random group was significantly slower at rule application than both the blocked and blocked IT conditions, and that there were no significant differences between the two blocked groups.

Errors. As expected, participants also made significantly more errors across all blocks in the random practice schedule as shown in Figure 13. In the first block, the

random group averaged 52.2 errors (SE = 4.28) as compared to errors made by the blocked and blocked IT groups (M = 7.7, SE = 1.45; M = 5.1, SE = 1.36, respectively). By the last block, this difference had decreased, and random was actually more accurate (M = 0.64 errors, SE = 0.22) than either blocked or blocked IT (M = 2.2, SE = 0.65; M = 2.6, SE = 0.67, respectively). There was a significant main effect of acquisition schedule, F(2, 39) = 31.72, of practice block, F(5, 195) = 77.86, and a significant interaction between the two factors, F(10, 195) = 48.66, all p's < .001. The random condition again made significantly more errors than the two blocked groups, as confirmed by Dunnett's post hoc comparisons. Not surprisingly, the blocked IT group's accuracy was not significantly different from that of blocked.

Retention

Rule selection. A significant contextual interference effect was observed in latency for choosing the rule, as well as for accuracy. Figure 14 shows the mean latency for choosing the correct rule across blocks in all three acquisition conditions. In contrast to acquisition performance, the random group performed significantly faster than the blocked group across all three blocks. In the first retention block, the random group averaged 5.1 s (SE = 0.29 s) to choose the correct rule, whereas the blocked and blocked IT groups averaged 11.0 s (SE = 0.73 s)and 11.4 s (SE = 0.91 s), respectively. This difference lessened in the third block, but the random practice group was still much faster (M = 3.8 s, SE = 0.18 s) than either blocked or blocked IT (M = 5.6 s, SE = 0.56; M = 5.4 s, SE = 0.32 s, respectively). An ANOVA revealed a significant main effect of practice schedule on rule selection time, F(2, 39) = 20.33, p < .001. There was also a main effect of block, F(2, 78) = 94.75, p < .001, a significant interaction between block and acquisition schedule, F(4, 78) = 12.61, p < .001. Dunnett's comparisons confirmed

that the random group performed significantly faster across all three blocks, and that there were no significant differences in reaction time between the two blocked schedules.

Rule application. The significant contextual interference effect that was found in rule application in Experiment 1 was only partially replicated, though the trends were mostly in the predicted direction. Table 1 shows the mean latency for rule application across blocks in all three acquisition schedules. Application of the rule showed a trend in the correct direction (of random responding more quickly than blocked); however, this was not significant, $p = 35$. The random group was slightly faster ($M = 3.26$ s) at applying the rule than the blocked group ($M = 3.32$ s), but only for the first retention block. There was a significant interaction between acquisition schedule and block, $F(4, 78) = 4.55$, $p = .004$, however there was no main effect of block.

Table 1. Mean rule application time (in seconds) across retention blocks for the three acquisition schedules

Schedule	Block 1	Block 2	Block 3
Blocked	3.32 (0.31)*	3.18 (0.32)	3.25 (0.36)
Blocked IT	3.99 (0.25)	3.78 (0.21)	3.49 (0.13)
Random	3.26 (0.22)	3.43 (0.26)	3.37 (0.25)

Note. *Standard errors (in seconds) are in parentheses

Errors. Figure 15 shows the mean number of errors across retention blocks for the three different practice conditions. As predicted, the random group performed with the greatest accuracy across all blocks in retention. In the first retention block, the random group averaged 1.6 errors, as compared to those made by the blocked and

blocked IT groups (M = 45.5, SE = 5.56 and M = 41.5, SE = 5.08 errors, respectively). By the last block, this difference lessened to random averaging no errors (M = 0.2, SE = 0.15), blocked averaging 12.1 errors (SE = 4.97), and blocked IT averaging 8.9 errors (SE = 4.36). An analysis of variance revealed this to be a significant difference, $F(2, 39) = 14.286$, $p < .001$. There was also a main effect of block, $F(2, 78) = 83.38$, $p < .001$, and a significant interaction between block and acquisition condition, $F(4, 78) = 18.30$, $p < .001$. Random performance was significantly more accurate than the two blocked groups, as confirmed by Dunnett's T3, and there was no significant difference between the blocked and blocked IT schedules.

Relational Processing

The results from both experiments were then compared and analyzed together to investigate the presence/contributions of relational processing. Experiment 1 utilized unique, unrelated symbols and math rules, while Experiment 2 used similar symbols with corresponding related rules.

Acquisition

Figure 16 shows mean reaction time for random and blocked conditions in both the unrelated (Exp.1) and related (Exp. 2) conditions. The blocked IT groups have been excluded from the figures for clarity, but were still included in the analyses. Overall, blocked IT performance mirrored that of the blocked group. Additionally, the actual application of the rules was not assumed to be significantly affected by relatedness, and so was not included in this analysis.

Rule selection. Analyses of variance (ANOVAs) were run on all data using an alpha level of .05. Specific pair-wise comparisons related to the hypotheses of the study were also conducted, with an adjusted α-level of .01 used for all t-tests. As before,

unequal variances were assumed due to the nature of the practice schedule design. A 6 x 2 x 3 mixed ANOVA (corrected by Huynh-Feldt) on these data show that relatedness had a significant effect on latency to choose the correct rule, revealed by a significant interaction between relatedness and block, $F(5, 390) = 2.97$, $p < .05$. Participants generally took less time choosing the correct symbol-rule pairing in the unrelated random condition (Exp. 1) as compared to the related random condition (Exp. 2), revealing the increased difficulty and workload created by the related set of symbols. This was especially evident in the first two practice blocks, where the unrelated random group outperformed the related random group by an average of 3.5 s. There were no significant differences between the two blocked conditions. There was also a significant three-way interaction of acquisition, relatedness and block, $F(10, 390) = 3.35$, $p < .01$. Planned-comparison tests revealed that this significant three-way interaction was due to the significantly larger difference between related and unrelated random groups (as opposed to blocked) in the first practice block, $t(26) = 2.12$, $p < .05$. However, there was no overall main effect of relatedness, $F(1, 78) = 1.657$, $p = .20$.

Errors. Figure 17 shows mean accuracy data for random and blocked conditions in both the unrelated (Exp.1) and related (Exp. 2) conditions. There was a significant interaction between relatedness and acquisition schedule for accuracy during acquisition, $F(2, 78) = 3.05$, $p = .05$, which describes the larger differences between the two random groups (as opposed to blocked) due to relatedness. Planned-comparisons using an alpha of .01 revealed marginally significant differences between the two random groups (all p's $< .04$) for blocks 4, 5 and 6. The related random group generally made fewer errors across blocks than the unrelated random group; however, there was no main effect of

relatedness, $F(1, 78) = 1.999$, $p = .16$. Again, there were no significant differences between the two blocked conditions.

Retention

Rule selection. Figure 18 shows mean rule selection time for retention for random and blocked conditions in both the unrelated (Exp.1) and related (Exp. 2) conditions. For the retention test, there was a significant main effect of relatedness on mean reaction time to choose the correct rule, $F(1, 78) = 6.78$, $p = .01$. There was also a marginally significant interaction between relatedness and acquisition schedule, $F(2, 78) = 2.76$, $p = .06$. The two random conditions performed equally well, whereas unexpectedly, the related blocked group responded more quickly than the unrelated blocked condition. Planned comparison tests revealed significant differences between the two blocked groups in retention block 2, and marginally significant differences for block 3, $p = .02$. This could be explained by the opportunity for random practice during the first block of retention for the blocked groups. The related "blocked" group may have learned the rules more quickly than the unrelated "blocked" group due to the ability to compare and contrast between trials and may show some evidence of relational processing.

Errors. There were no significant effects of relatedness on retention accuracy; however, the unrelated random and blocked groups made consistently more errors than the related conditions across all blocks of retention. Figure 19 shows mean retention accuracy data for random and blocked conditions in both the unrelated and related conditions.

Comparing the two experiments, there was some evidence of relational processing. Relatedness had a significant effect on latency for both acquisition and retention. Participants generally took less time choosing the correct symbol-rule pairing

in the unrelated random condition (Exp. 1). This could reflect the extra time spent contrasting and discriminating between the symbols (and rules) in the related random group, and also reflects the heightened difficulty and increased workload of the related set of symbols. This trend was reversed in retention, with unrelated groups responding slower than related. The extra cognitive work spent discriminating between the related, and thus highly similar, rules might have led to quicker performance in choosing the rules on the retention test. There were also significant interactions between relatedness and acquisition schedule, and also between all three factors, which describe the larger differences between the two random groups (as opposed to blocked) due to relatedness, especially in the early practice blocks.

Relatedness also had a small but significant effect on accuracy during acquisition. Though the unrelated rules were faster, they generated slightly more errors during random acquisition than did the related symbols. The related random condition was slower during acquisition, yet made fewer errors. This may reflect the extra discrimination needed to choose the correct rule amongst highly similar rules corresponding to similar symbols. Another hypothesis could entail a speed-accuracy trade off. The same instructions of giving equal attention to both accuracy and speed were given to both the unrelated and related groups, but it is possible that the unrelated group as a whole focused on speed, whereas the related group focused on accuracy. However, the related group did respond significantly faster than the unrelated group after a 48-hour retention period. This could lend credibility to the relational processing theory, as it infers that deeper processing and more cognitive work has taken place during the acquisition period. Alternatively, one could suggest that the focus on accuracy rather than speed in the related group led to better performance on the retention test. More research is needed

to parse out which of these explanations could be the cause of the discrepant results for choice reaction time and accuracy. Overall, however, the present results provide little support for an important role of intraitem, relational processing in producing the contextual interference effects on retention in this task.

As in Experiment 1, we were unable to replicate the demands (or performance) of a random schedule with a blocked-plus-intervening-task acquisition schedule (blocked IT). Based on the study by Carlson and Yaure (1990), a blocked schedule with an intervening task was included in both Experiments 1 and 2. These experiments did show a significant contextual interference effect between blocked and random performance on this novel task involving sequential mathematical rules. Results from Experiment 2 mirror that of Experiment 1, however, with no significant differences found in either acquisition or retention between the blocked IT schedule and a classic blocked schedule. The results of Experiments 1 and 2 revealed that introducing an intervening task between trials in a blocked schedule did not lead to performance similar to that of random practice, as hypothesized by Carlson and Yaure (1990). Participants responded to two math verification problems between each trial in blocked practice; however, both acquisition and retention performance in this condition looked remarkably like that of blocked performance.

The results from Experiments 1 and 2 lead to the question of whether the intraitem processing (rule retrieval) view can be properly investigated through the use of the intervening task paradigm. Acquisition performance in Carlson and Yaure's (1990) study suggests that one math verification problem was not enough to 'clear out' working memory in a blocked practice schedule, as they had posited. In the present experiments, two math problems were also apparently not enough to clear out working memory and

cause the retrieval of the rule from memory, based on the superior acquisition performance of this group.

It is possible that Carlson and Yaure saw increased performance of the blocked IT group on their transfer test because it was an immediate transfer to a problem-solving task. Blocked or massed schedules often lead to inflated performance on immediate tests, but then reveal dismal performance on tests of long-term retention (Keppel, 1964). This immediate transfer test might have accentuated the differences that might have disappeared if a longer retention interval was utilized. Also, by nature of the task design, the blocked IT group spends a longer amount of time per rule. Since only one math problem intervened in their study, it is conceivable that the rule could stay in working memory throughout the inter-trial interval (see Experiment 1 discussion above), and participants have more time to rehearse the rule between trials than in the classic blocked schedule. Since small effects of maintenance rehearsal can often be seen in immediate testing, it is possible that the longer opportunity for maintenance rehearsal of the rules in the blocked IT schedules led to superior immediate performance over the blocked schedules (see Naveh-Benjamin & Jonides, 1984).

To summarize, in a blocked practice schedule, there is only one rule that needs to be retrieved, so it is possible that the relevant procedure or rule stays 'activated' in memory and thus is more easily accessible, even when in an intervening task paradigm. In blocked schedules, there is no interference from other rules in the study, and it may be that the interference caused by an intervening task is not sufficient to recreate the demands of a random schedule, as evidenced by the superb acquisition performance by blocked IT groups. Retrieval demands (in the form of proactive interference from the other to-be-learned rules) may contribute to the decrease in acquisition performance in

random schedules. Greater interference, and hence, more cognitive work during learning leads to longer latencies and more errors in acquisition, but increased retention performance. This possibility was explored in Experiment 3.

Figure 9. Kanji symbols with common elements

Figure 10. Sets of related symbols and rules in Experiment 2.

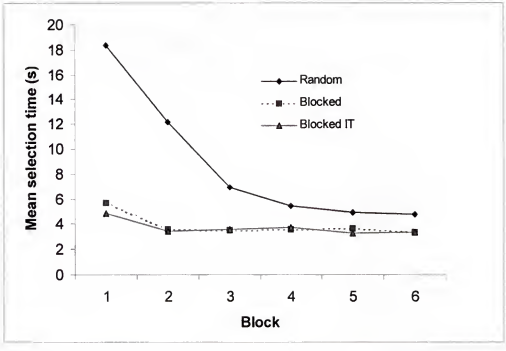

Figure 11. Mean time (in seconds) to select the correct rule across practice blocks for each of the three acquisition conditions

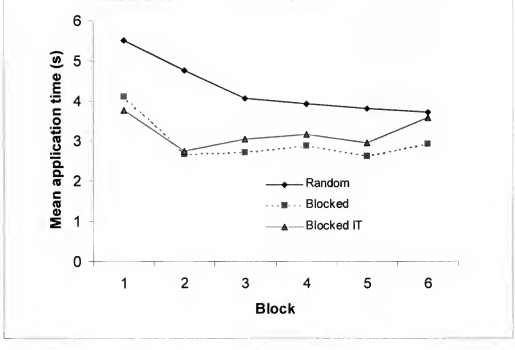

Figure 12. Mean rule application time (in seconds) across practice blocks for the three acquisition schedules

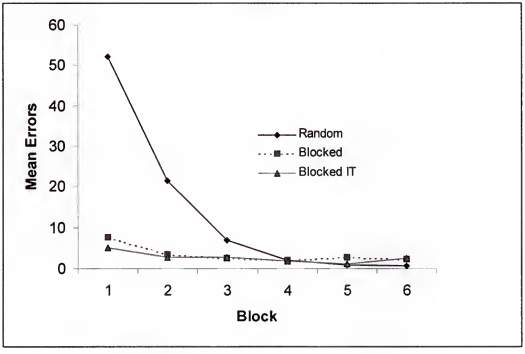

Figure 13. Mean number of errors across practice blocks for the three acquisition conditions

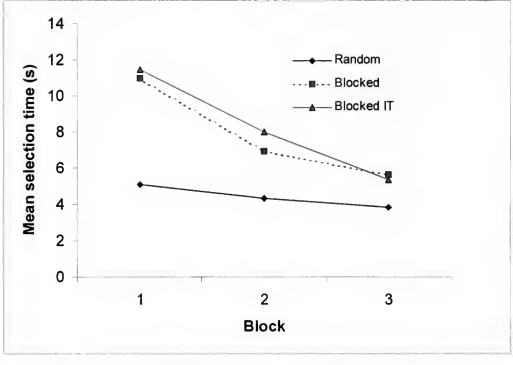

Figure 14. Mean time (in seconds) to select the correct rule across retention blocks for each of the three acquisition conditions

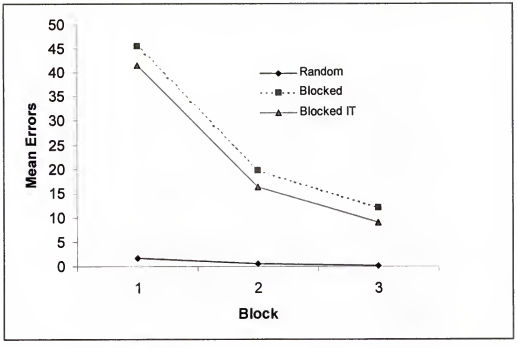

Figure 15. Mean number of errors across retention blocks for the three acquisition conditions

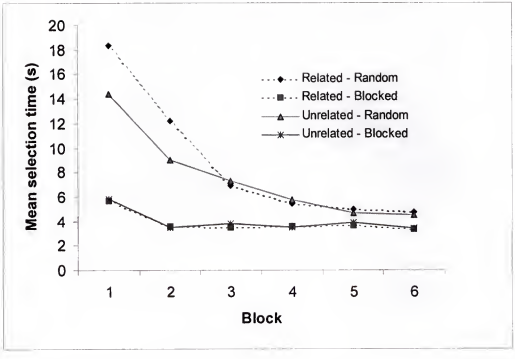

Figure 16. Mean time (in seconds) to select the correct rule across practice blocks for random and blocked acquisition schedules in Exp. 1 (unrelated symbols and rules) vs. Exp. 2 (related symbols and rules)

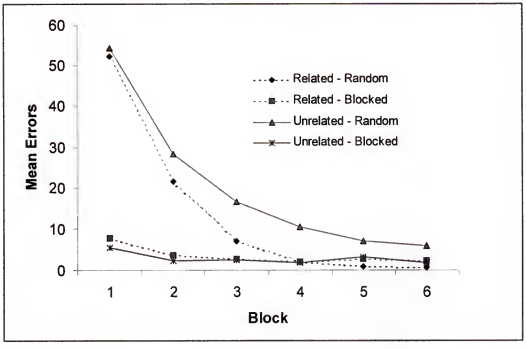

Figure 17. Mean number of errors across practice blocks for random and blocked acquisition schedules in Exp. 1 (unrelated symbols and rules) vs. Exp. 2 (related symbols and rules)

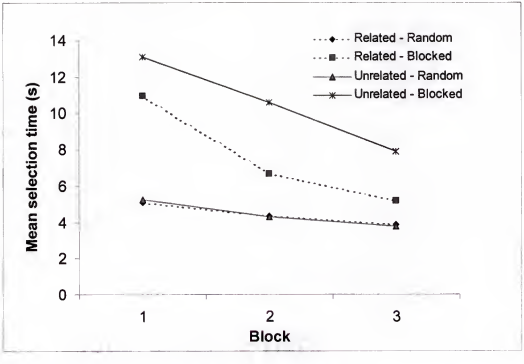

Figure 18. Mean time (in seconds) to select the correct rule across retention blocks for random and blocked schedules in both the unrelated (Exp.1) and related (Exp. 2) conditions

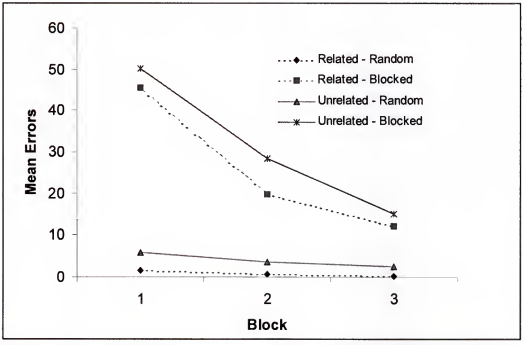

Figure 19. Mean number of errors across retention blocks for random and blocked schedules in both the unrelated (Exp.1) and related (Exp. 2) conditions

EXPERIMENT THREE

Even though the comparison of Experiments 1 and 2 revealed an effect of relational processing, the differences were quite small compared to the overall contextual interference effect. The presence of related symbols with corresponding rules significantly affected mean reaction time to choose the correct rule, with the related random groups choosing the correct rule more slowly during the learning phase. This pattern was reversed 48 hours later on the retention test, with the related group responding with the correct rule significantly faster than those learning the unrelated, unique rules. On the other hand, although there was no significant effect of relatedness on accuracy, there was a trend for the related group to make fewer errors during acquisition. In view of this apparent trade off, and of the proportionally large overall contextual interference effect of random vs. blocked practice, further investigation into relational processing with the present task paradigm did not seem warranted.

Although the direct evidence for relational processing in the random practice was therefore quite modest, the failure of the blocked-IT conditions in either experiment to produce a contextual interference effect in acquisition weakens its value as a test of the intraitem processing hypothesis. Carlson and Yaure (1990) had attempted to add interference into a blocked schedule via intervening tasks to induce the same workload as a random schedule. Interference of this form is not easily added into a blocked schedule, because regardless of the difficulty of the intervening task, there is still only one rule to be learned at a time. Retrieval demands (in the form of proactive interference from the

other to-be-learned rules) may be a factor leading to the decrease in acquisition performance in random schedules. We have argued that the absence of proactive interference in the blocked-IT condition makes it equivalent, in terms of retrieval practice, to the traditional blocked practice schedule. Rather than adding interference to a blocked schedule, then, an attempt was made in Experiment 3 to decrease the amount of proactive interference in a random schedule, creating two semi-random acquisition schedules.

The random versus blocked contextual interference effect is replicated with a different participant pool (higher level cognitive and developmental psychology classes), adding to the reliability and generalizability of the results. As before, the random group learns the six sequential mathematical rules with all rules appearing randomly throughout six blocks, and the blocked group learns one mathematical rule per block. Both have the same number of trials per rule. In addition, there are two "semi-random" conditions, with one group learning two rules per block and another group learning three rules per block.

A question that arose during the design of this experiment was whether or not the two-rule group should be given the rules in a strictly alternating schedule. It was decided that the rules in the two-rule group should be learned in a “random” schedule rather than in an alternating schedule, since if the rules alternated they will also necessarily be predictable. Schneider et al. (1995) showed that unpredictability of the rules also contributed to the contextual interference effect. They claimed that the predictability of the rules (in their serial group) aided during acquisition in that it allowed participants to "pre-load" or anticipate the rule in memory for each trial.

In a sequential learning schedule with the present task, the pairing of the symbol and rule would be much less important than with a random schedule, since participants

could rely on the sequence of rules, and not encode the corresponding symbol. This may also contribute to the poor retention performance in blocked schedules, as the symbols do not need to be differentiated at study in order for participants to "learn" the rule. Since participants may rely solely on knowing which rule to apply beforehand, in these situations the pairing between symbol and rule becomes irrelevant. Based on these considerations, the two- and three-rule groups are presented with the rules in random order in each block.

A potential hypothesis regarding the contrast of the semi-random and random schedules is that any intervening activity between trials in a "blocked" schedule, especially a highly similar, intrusive task (such as learning another rule) would lead to performance similar to that of random practice. If, in essence, the clearing out of working memory and retrieving of the rule on each trial in acquisition is all that is needed to see a benefit in retention (i.e. intraitem processing), then we would expect both two- and three-rule conditions to perform comparably to the pure random group in acquisition and retention. This must be differentiated from the intervening task conditions such as those utilized by Carlson and Yaure (1990) and in Experiments 1 and 2 presented here. We have shown that an intervening task of math verification is not sufficient to clear out working memory between trials. The key difference is the similarity in the procedural activity of the intervening material. If participants are engaging in the same type of processing, namely the same procedures, for both the main and secondary tasks, then we might expect that working memory would indeed be sufficiently cleared.

For Experiment 3, participants perform multiple rule mappings and applications between each repetition of a rule, as opposed to the math verification task, thus equating the processing demands of both the main and secondary tasks. It must be noted that the

"secondary task" is really not such. The intervening material is also material to-be-remembered (i.e. other symbol/rule pairings) and the average amount of intervening activity will be manipulated through the two- vs. three-rule groupings.

On this "displacement" account, then, the clearing out of working memory due to the retrieval and application of the rule on each trial in acquisition would lead to a benefit in retention (i.e., intraitem processing). More specifically, we would expect both two- and three-rule conditions to perform comparably to the pure random group in acquisition and retention.

However, if the contextual interference effect is driven by the amount of potentially interfering material (i.e. the other symbols and rules) present within a block, then the two- and three-rule groups should fall proportionately between pure random and pure blocked schedules. In the pure random group, there are six concurrent rules to-be-learned. In each trial, a participant needs to load one rule, out of a potential six in memory. In a three-rule condition, a participant would still need to load the correct rule; however, the search set has decreased from six to three. This may not make much of a difference in the first few trials; but in later trials, after the identity of the smaller set has been learned, the participant can decrease the search set and will only need to have these three rules available at the start of each trial.

Therefore, by systematically decreasing the retrieval demands (i.e., proactive interference) per block, participants should have shorter latencies and make fewer errors during acquisition than those in a pure random condition. The three-rule semi-blocked group should reveal acquisition performance roughly halfway between that of pure random and pure blocked. If half of the search set is removed and there are only three rules that must be available for retrieval, one would expect a proportional decrease in the

amount of search time. In Experiment 1, it took the random group almost three times as long to select the correct rule ($\underline{M}$ = 14.4 s) as the blocked group ($\underline{M}$ = 5.8 s) for the early practice blocks. This difference lessened across practice blocks, yet the random group still responded more slowly than the blocked group, even in the last practice block. The improvement in speed for the random acquisition group followed a power function, revealing a faster rate of improvement than either of the blocked conditions.

Plotting these functions on a log scale, and calculating best fits, revealed that the random group function was nearly a straight line. Using the proportional search set sizes for the two- and three-rule conditions, predicted best fit lines were plotted for these two acquisition schedules based on the random and blocked data from Experiment 1. These preliminary predicted acquisition functions can be seen in Figure 20. However, the predicted functions for the two- and three-rule schedules will be recalculated based on the reported data from the random and blocked groups in Experiment 3. The predicted power functions for the four acquisition schedules are listed in Appendix C.

In keeping with the same hypothesis, the retention performance of the two semi-blocked groups should then also fall between the retention performance of the pure random and pure blocked groups. Less interference (than pure random) should lead to better performance during acquisition in both groups, with the two-rule group very close to blocked performance. However, there is still more interference present per block in both semi-blocked groups than in the pure blocked, which should consequently lead to these groups retaining more information over a delay than the completely blocked group. In the first retention block of Experiment 1, the random group selected the correct rule ($\underline{M}$ = 5.2 s) approximately 2.5 times faster than the blocked group ($\underline{M}$ = 12.9 s). Both followed a linear function across retention blocks, with the blocked group performing at

faster rate than random. This reflects the blocked group's learning of the rules due to the random presentation over the three retention blocks.

Keeping the predictions proportional (and based on the estimated acquisition functions), we can expect the three-rule group to respond somewhat faster than the blocked group in the first retention block and the two-rule group to respond closer to the blocked group. Once again using the proportional search set sizes for the two- and three-rule conditions, predicted best fit lines for retention were plotted (based on Exp. 1 data) and can be seen in Figure 21. The predicted linear functions for retention are also listed in Appendix C.

In summary, if the amount of proactive interference, as defined by the number of concurrently "active" symbols and rules, determines the degree of contextual interference, then the incremental amounts of interference, and hence increasing retrieval demands (from pure blocked, to the semi-blocked groups, to random) should lead to proportionately stacked performance in both acquisition and retention (as predicted in Figures 20 and 21). Alternatively, if any sufficiently difficult intervening task between repetitions of a rule (such as learning a different rule) is enough to displace the prior rule from working memory and force participants to reload the required rule on every trial, than the two- and three-rule groups' performance should be very similar to that of the random group.

Method

Participants

Seventy undergraduates (19 males, 51 females) at the University of Florida participated in this experiment. Participants were randomly assigned to the four experimental groups. Two participants' data were discarded (2 females), as they were not

able to finish the acquisition blocks within the allotted time. This left 68 participants, with 17 participants per group. They received extra credit on an exam in either a cognitive or developmental psychology class. Motivation to perform well, as well as to return for the second part of the experiment, was provided in the form of a monetary reward ($40) for the best few participants. As many as eight participants were tested at the same time.

Materials and Apparatus

The software and set up were identical to that of Experiments 1 and 2. This experiment utilized the stimuli set of unrelated symbols and rules as in Experiment 1 (see Appendix A).

Design

The design for the acquisition phase was a 4 x 6 mixed factorial. Acquisition condition was varied between subjects (random, blocked, two-rule, and three-rule) and practice block was varied within subject. The design for the retention phase was a 4 x 3 mixed factorial, with acquisition condition manipulated between subjects, and block manipulated within subjects.

Procedure

The participants learned the six symbolic mathematical rules in one of four acquisition schedules: random, blocked, two-rule and three-rule. Participants in all groups practiced the rules for six blocks of 30 trials (180 trials). The random group learned the six symbolic rules in random order (5 trials each per block). In the blocked condition, each block included 30 trials with a single rule and the order in which rules appeared was counterbalanced. The two-rule group learned the rules in pairs, with only two symbols appearing per block. The three-rule group learned the rules in groups of three per block.

The presentation of symbols in the two- and three-rule groups was pseudo-random, and the order of symbols (across blocks) was counterbalanced across participants.

The step-by-step procedure outlined in Experiment 1 was the same for Experiment 3.

Results and Discussion

As in Experiments 1 and 2, results are presented for three dependent variables for both acquisition and retention: 1) mean reaction time to select the correct rule, 2) mean latency to apply the correct rule, and 3) the mean number of errors during rule selection. Two participants' data were excluded from the analysis, due to unfinished acquisition sessions.

Acquisition

Rule selection. Participants in the random group responded significantly slower when choosing the correct rule across all blocks of acquisition. Figure 22 displays the mean latency for choosing the correct rule across practice blocks for all four acquisition schedules. The random group was approximately three times slower ($\underline{M}$ = 15.1 s, SE = 1.55 s) than the blocked group ($\underline{M}$ = 5.0 s, SE = 0.36 s) for the first practice block. The two-rule and three-rule response times fell in-between, with times closer to that of the random group ($\underline{M}$ = 9.8 s, $\underline{SE}$ = 0.99 s; $\underline{M}$ = 12.0 s, $\underline{SE}$ = 0.91 s, respectively). These differences lessened by the last practice block, with random now responding more quickly ($\underline{M}$ = 4.2 s, $\underline{SE}$ = 0.52 s) than the two- or three-rule groups ($\underline{M}$ = 4.9 s, $\underline{SE}$ = 0.69 s; $\underline{M}$ = 4.6 s, $\underline{SE}$ = 0.29 s, respectively). Random and three-rule acquisition followed power functions, revealing faster rates of improvement than the blocked or two-rule conditions. However, the three random and semi-random groups never achieved latencies as fast as the blocked group ($\underline{M}$ = 3.4 s, $\underline{SE}$ = 0.27 s).

Analyses of variance (ANOVAs) were performed on all data using a significance level of .05, and were corrected for sphericity by the Huynh-Feldt statistic. A 6 x 4 mixed ANOVA on these data show that there was a significant main effect of acquisition schedule on time to choose the correct rule, $F(3, 64) = 16.01$, $p < .001$. There was also a significant main effect of practice block, $F(5, 320) = 86.49$, $p <. 001$, and a significant interaction between acquisition schedule and block, $F(15, 320) = 10.18$, $p < .001$. The random group improved more rapidly across blocks than the other conditions, as can be seen in Figure 22.

Specific pair-wise comparisons were conducted using an adjusted α-level of .01 for all t-tests. Dunnett's T3 comparisons revealed that the random group was only significantly slower than the blocked condition. The blocked group was significantly faster than all three other conditions, all p's < .001.

In the first acquisition block, the reaction times to choose the correct rule were ordered as follows: blocked, two-rule, three-rule, and random in order of fastest to slowest (see Figure 22). Specific pair-wise comparisons (with an adjusted α-level of .02) on just the first block revealed that the blocked group was significantly faster than all other groups, and the two-rule group was significantly faster than random

Rule application. As in the first two experiments, there was a trend toward faster rule application times for the blocked groups during acquisition. However, as in Experiment 2, this failed to reach significance, $p = .12$. The three semi-random and random conditions did not differ significantly from one another in mean rule application time.

Errors. As expected, participants also made significantly more errors across all blocks in the random practice schedule as shown in Figure 23. In the first block, the random group averaged 49.5 errors (SE = 4.6) to the blocked group's 7.2 errors (SE = 2.0). The three-rule and two-rule groups averaged 31.7 errors (SE = 4.1) and 21.5 errors (SE = 3.4), respectively. By the last block, these differences had decreased, but random was still less accurate (M = 3.4 errors, SE = 2.3) than blocked (M = 2.2 errors, SE = 0.4) or three-rule (M = 2.7 errors, SE = 1.7). The two-rule group still had a mean of 5.5 errors (SE = 2.3) by the last practice block. An ANOVA revealed that there was an overall significant main effect of acquisition schedule, $F(3, 64) = 10.29$, $p < .001$. There was also a main effect of practice block, $F(5, 320) = 106.22$, and a significant interaction between the two factors, $F(15, 320) = 15.54$, p's $< .001$. Again, the random group improved more quickly than the other three groups. Dunnett's t-tests revealed that the blocked group made significantly fewer errors than the other three groups, all p's $< .002$. While there was a trend of decreasing accuracy for the other conditions (from two-rule to random), there were no significant differences between the random, three-rule, or two-rule schedules.

However, there were significant differences between the random group and both the two- and three-rule groups in the first practice block, with both groups making significantly fewer errors than the random group. The two- and three-rule groups were not significantly different from one another in this first block.

Retention

Rule selection. A significant contextual interference effect was observed in latency to choose the correct rule, as well as for accuracy. Figure 24 shows the mean latency for choosing the correct rule across blocks in all four acquisition conditions. In

contrast to acquisition performance, the random group performed faster than the other three groups across all three blocks. In the first retention block, the random group averaged 5.1 s (SE = 0.36) to choose the correct rule, whereas the blocked group averaged 11.1 s (SE = 1.07). The two- and three-rule groups retained the rules better than blocked, with means in the first block of 7.9 s (SE = 0.75) and 6.9 s (SE = 0.86), respectively. The difference lessened in the third block, but random practice was still faster (M = 3.8 s, SE = 0.29) than blocked (M = 5.6 s, SE = 0.45), two-rule (M = 4.7 s, SE = 0.65) and three-rule (M = 4.2, SE = 0.31).

A 3 x 4 ANOVA confirmed that there was an overall significant main effect of acquisition schedule, $F(3, 64) = 13.39$, $p < .001$. There was also a main effect of block, $F(2, 128) = 63.82$, $p < .001$, and a significant interaction between block and acquisition schedule, $F(6, 128) = 4.56$, $p = .002$. Whereas the random and semi-random groups performed well across all retention blocks, the blocked group improved at a faster rate, as this was the first exposure to a random test schedule for this group. Dunnett's t-tests revealed that the blocked group was significantly slower than all other groups, while the two-rule group was significantly slower than the random group.

Rule application. Unlike Experiment 1, there was no contextual interference effect for rule application.

Errors. As previously mentioned, a significant contextual interference effect was also observed for accuracy. Figure 25 shows the mean number of errors across blocks in all four acquisition conditions. In contrast to acquisition performance, the random group made virtually no errors, outperforming all three groups. The random group averaged 3.1 errors in the first block (SE = 1.2), while the three- and two-rule averaged substantially more (M = 11.8 errors, SE = 3.3, and M = 18.6 errors, SE = 3.4, respectively). The

blocked group performed significantly worse, with a mean of 44.8 errors (SE = 4.9) in the first retention block. This was confirmed by an ANOVA, which revealed a significant main effect of acquisition schedule, $F(3, 64) = 17.94$, $p < .001$. Dunnett's t-tests showed that the blocked group made significantly more errors than the other groups across all blocks, and the two-rule group made significantly more errors than the random group. These differences in error rates between groups lessened by the last retention block (most likely due to the random practice during test), with the random group averaging less than one error by the last retention block. The blocked group had a faster rate of improvement than the other groups, but still had a mean of 12.9 errors (SE = 3.8) by the last block. This was confirmed by a significant main effect of block, $F(2, 128) = 79.53$, and a significant interaction between block and practice schedule, $F(6, 128) = 16.03$, both p's $< .001$.

The results from Experiment 3 replicated the strong contextual interference effect between blocked and random performance in symbolic rule learning found in the previous two experiments. The random group suffered during acquisition, with significantly longer reaction times and more errors than the blocked group. However the extra cognitive work during random acquisition helped this group substantially outperform the blocked group (in both latency and accuracy) during retention.

Analysis of the performance of the semi-random acquisition groups provides some interesting findings. During the acquisition phase, the two- and three-rule groups responded more quickly than the random group, yet not as fast as the blocked group. The prediction of decreasing reaction times (random, three-rule, two-rule, and blocked, respectively) was indeed confirmed when looking at the first few practice blocks. However, the differences between groups lessened as participants had more practice at

the task. The blocked group performed significantly faster than all other groups across all blocks of the acquisition phase.

The "displacement" hypothesis described above proposed that if the clearing out of working memory and retrieving of the rule on each trial in acquisition was all that was needed to see a benefit in retention, then both two- and three-rule conditions would perform similarly to the pure random group in acquisition and retention. Alternatively, it was hypothesized that if we instead expected the amount of proactive interference from other active symbols and procedures in the block to have a significant effect on the amount of contextual interference, than the two- and three-rule groups would fall proportionately between pure random and pure blocked schedules, due to the decreased search set sizes.

Although the performance of the two- and three-rule groups fell in-between that of random and blocked, as predicted by the interference view, the means fell closer to that of the random group than would be expected on that view. Consistent with a displacement view, it seems that a very similar and demanding task between repetitions of the rules (i.e. the retrieving of a similar rule to-be-learned) was enough to clear out working memory, forcing participants to reload the rule on every trial. This seemed to be the case in even the two-rule condition. Even though there were only two rules that needed to be kept in mind across trials, with many (random) repetitions of rules across successive trials within the blocks, the active processing needed to choose the correct rule, and then apply that rule, was enough to take up most of working memory resources. Participants could not hold both rules in working memory across trials, as evidenced from the slow reaction times during acquisition. Impressively, having to deal with just a single additional symbol-rule was enough to produce almost half of the interference found with

six rules during acquisition (see Figure 22), and almost half the retention benefit found with six rules in long-term retention (see Figure 24).

Yet we can also argue that the number of rules that are learned simultaneously (six, three, two, or one) may lead to qualitative differences in acquisition performance as well. The largest difference between groups was found in the early practice blocks. The predicted "stacked" reaction times were found, with random performing the slowest during learning, the three-rule responding the next fastest, then the two-rule, and finally, blocked had the quickest reaction times. The predicted functions for the two- and three-rule schedules were recalculated based on the reported data from the random and blocked groups in Experiment 3. The actual and predicted functions for the two semi-random conditions are shown in Figures 26. (Figure 27 shows these functions plotted on a log scale.) For comparison, the actual best fit functions for acquisition and retention for the two- and three-rule schedules (along with the predicted functions) are listed in Appendix C.

This "stacked" result can be discussed in terms of the retrieval demands inherent in each acquisition schedule. In the random schedule there are six concurrent rules to-be-learned, and for each trial, a participant needs to load into working memory one out of a potential six rules stored in memory. In the three-rule (or two-rule) condition, participants still need to load the correct rule; however the search set has now decreased. After several trials, the participant should be aware of the size of the search set and will only need to have these three (or two) rules available at the start of each trial. This is similar to Schneider et al.'s (1995) results for their serial acquisition condition. Participants in the serial, two- and three- rule schedules all need to engage in intraitem processing (loading the rule into working memory for each trial). However, in the two- and three-rule

schedules, no rule can be "pre-loaded" as in the predictive serial condition. The rules in the two- and three-rule schedules were presented in a pseudo-random fashion. Yet instead of retrieving one rule out of a possible six rules (as in the random condition), there are only two or three rules from which to choose, leading to a faster search through memory and a faster mean reaction time in choosing the correct rule. This is still qualitatively different from the blocked schedule in which the rule is the same on every trial and can remain in working memory across multiple trials.

However, since the effect of proactive interference was marginal, we can assume that the two- and three-rule practice schedules cleared out working memory enough to show a performance gain at retention. The similarity in processing activity between rule repetitions was sufficient to require that participants engage in intratask processing and reload the rule on every trial. The performance of these two 'semi-random' groups, though stacked in the predicted direction, was not significantly different from that of the random group. Retention results also reveal that the two- and three-rule acquisition schedules required much more cognitive effort during learning than the blocked schedule, as these groups performed much closer to random performance than to blocked during both acquisition and retention. These results lend support to the idea that the two- and three-rule acquisition schedules afforded intraitem processing much like the random schedule, and created a mental workload at acquisition that was similar to that of a random schedule.

The question remains whether interitem, relational processing is playing much of a role in the present contextual interference effects. This seems unlikely, first, because the symbol-rule sets were drawn from Experiment 1, where we have argued there is little basis on which to do this sort of contrastive and organizational processing. Second, and

perhaps more importantly, the fact that the two-rule condition produced a robust contextual interference effect in acquisition and in long-term retention strongly implies that even when there are minimal opportunities for interitem processing within a block, the need to reload patterns and rules into working memory produces the kind of cognitive work that consolidates long-term memory for that material.

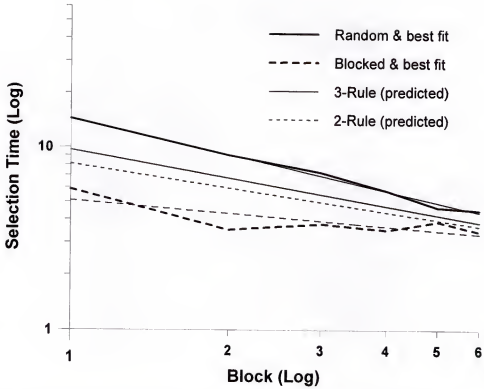

Figure 20. Predicted power functions for two- and three-rule acquisition conditions, based on the best fits for the random and blocked conditions from Exp. 1

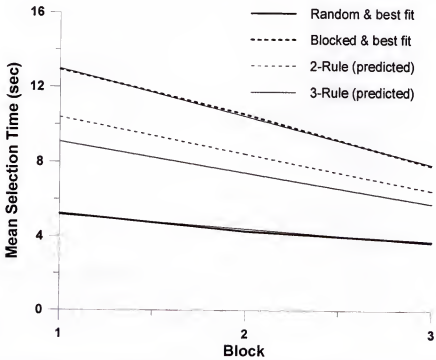

Figure 21. Predicted retention functions for two- and three-rule acquisition conditions, based on the best fits for the random and blocked conditions from Exp. 1

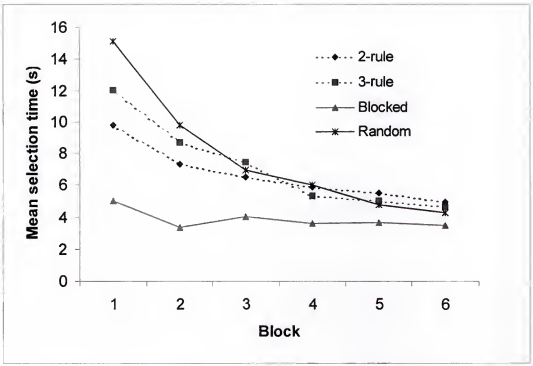

Figure 22. Mean time (in seconds) to select the correct rule across practice blocks for each of the four acquisition conditions

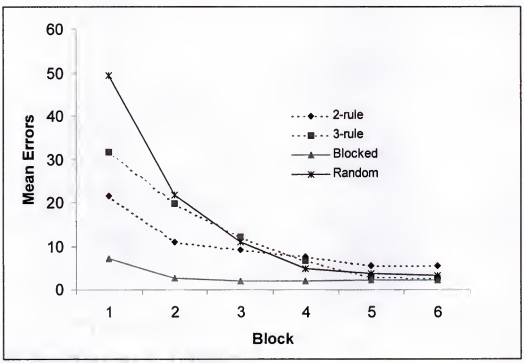

Figure 23. Mean number of errors across practice blocks for the four acquisition conditions

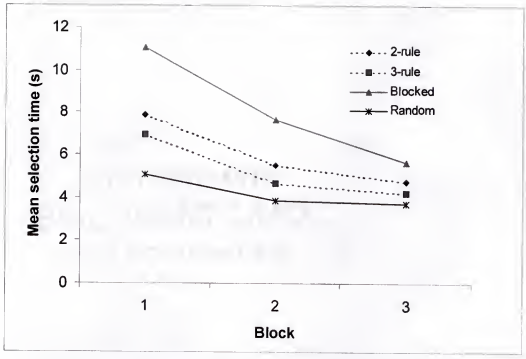

Figure 24. Mean time (in seconds) across retention blocks to select the correct rule for each of the four acquisition conditions

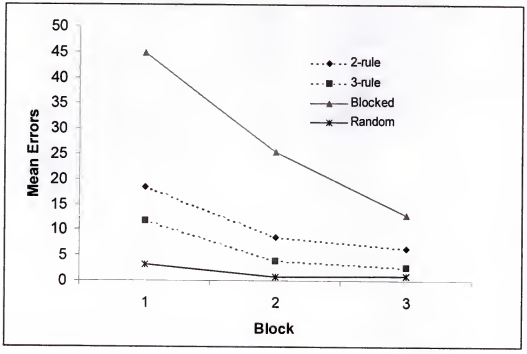

Figure 25. Mean number of errors across retention blocks for the four acquisition conditions

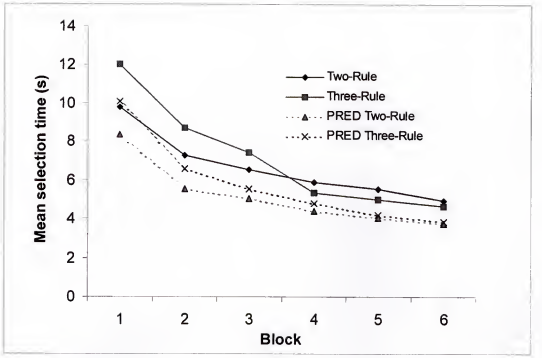

Figure 26. Predicted and actual rule selection time functions (in seconds) for the two-rule and three-rule acquisition schedules

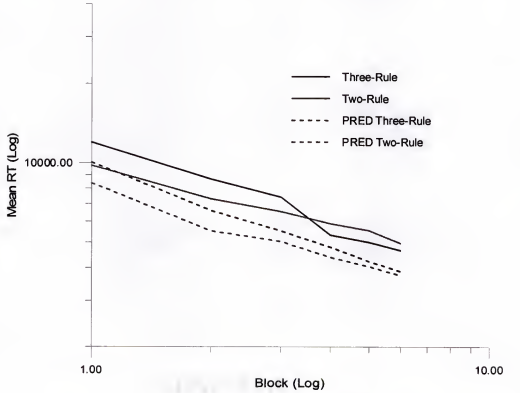

Figure 27. Predicted and actual reaction time power functions (log scale) for the two-rule and three-rule acquisition schedules

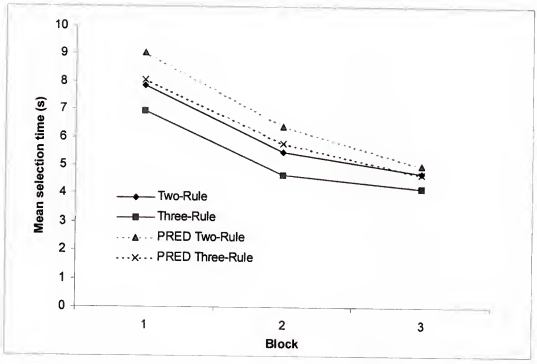

Figure 28. Predicted and actual rule selection time functions (in seconds) for the two-rule and three-rule acquisition schedules during retention

GENERAL DISCUSSION

The *contextual interference effect* occurs when randomly-varied practice on a set of items results in poorer performance than does practice blocked by items during acquisition, but better subsequent long-term retention of the information that has been learned (Battig, 1972). Three experiments were conducted to see if contextual interference effects were to be found in a novel, complex cognitive skill involving unfamiliar symbols and computational rules, and to evaluate several proposed explanations of the effect. Participants learned a set of Japanese symbols mapped onto mathematical rules in either a blocked or random practice schedule. A blocked schedule with an intervening task was also included to further explore Carlson and Yaure's (1990) finding that random-like cognitive processing during learning could apparently be produced with an irrelevant but demanding intervening task, simulating the effects of a spaced practice schedule.

The results from all three experiments revealed a strong contextual interference effect in learning the novel sequential mathematical rules paired with Japanese Kanji symbols. In the present set of experiments, all blocked-practice groups yielded significantly faster and more accurate responses than the random-practice groups during acquisition. As predicted, this trend was reversed in retention, with the random-practice groups performing more quickly than the blocked-practice groups, and making very few errors. Practice at retrieving and loading the rule into working memory on every trial (as

in random practice) led to better performance in subsequent retention, where it is also necessary to retrieve the same procedures from memory.

Most of the literature describing contextual interference effects continues to be in the motor skill domain. Few studies have looked at contextual interference in the learning and retention of cognitive skills, with the exception of two studies on the learning of Boolean logical rules (Schneider et al. 1995; Carlson and Yaure, 1990). The present studies have revealed a substantial contextual interference effect for a rather novel task of pairing symbols with mathematical rules.

In Experiment 1, this effect was seen not only in rule retrieval (of the correct symbol-rule pair), but also in the application of that rule to novel sets of numbers. This novel result of contextual interference effects in rule application found in Experiment 1 was only partially replicated in Experiment 2, however. The blocked group did apply the rules significantly faster than did the random group during acquisition, though there were no significant differences between the two groups at retention. There were no significant effects of practice schedule on rule application in Experiment 3, however.

As previously mentioned, the studies presented in this paper investigated two different types of processing inherent in various practice schedules, and how they contribute to contextual interference. Intraitem processing theories focus on the reconstruction of to-be-learned items from memory during acquisition, whereas interitem or relational processing theories focus on comparisons and contrasts between items during learning.

The use of novel Kanji characters provided the opportunity to represent relations between the rule symbols that correspond to relations in the mathematical rules. Experiment 1 utilized unique, unrelated Kanji symbols and math rules, and investigated

the presence of contextual interference effects for a high-level, yet novel, cognitive skill. Experiment 2 used symbols with common elements that corresponded to similar sequential math rules to investigate the contributions of relational processing, if any, to these interference effects. It was hypothesized that the random practice schedule in Experiment 2 should allow participants greater opportunities to compare and contrast between the different rules (and their corresponding symbols), since it allows for the grouping of related elements in memory that is not available when learning one rule at a time (blocked). This was expected to lead to a greater difference between blocked and random retention performance than that found in Experiment 1. Small, but notable effects of relational cues were found; the related symbol set of Experiment 2 led to worse performance than the unrelated set of Experiment 1 during acquisition, but subsequently showed better performance at retention, at least in terms of the speed of finding the correct rule.

An important finding of Experiments 1 and 2 was the demonstration that the blocked-plus-intervening task practice schedule was associated with acquisition performance much more like that of a traditional blocked than random schedule, and so it cannot function as a test of the intraitem versus relational processing account of contextual interference. As described previously, Carlson and Yaure (1990) had inserted four different processing and/or storage tasks between trials in a blocked schedule to attempt to clear out working memory between repetitions of the same Boolean rule. They claimed that an intervening task of math verification incorporated into a blocked schedule could induce the same retrieval workload and therefore reproduce the performance of a random schedule. Evidence for this claim came from transfer performance for the math verification blocked IT group (their Exp. 3) that was similar to random transfer

performance in Exp. 1. Based on this study, a blocked schedule with an intervening task was included in the present Experiments 1 and 2. In neither experiment were we able to replicate the demands (or performance) of a random schedule with a blocked-plus-intervening-task acquisition schedule.

Nonetheless, this finding can be interpreted as at least consistent with the intraitem processing view of contextual interference. A blocked practice schedule does not afford the clearing out of working memory between each trial of learning, even with an intervening task of moderate difficulty (math verification). This may be due to the fact that there is only one rule that is being learned at a time, and this can be kept in "long-term" working memory across trials. Less processing, then, is needed for the next repetition of the rule, as it has already been activated in memory and is easily accessible or retrievable.

This can be likened to the deficient-processing theorists' claim that the second occurrence of an item repeated in massed fashion receives less processing, or shallower processing, than does the second occurrence of a spaced item (Cuddy & Jacoby, 1982; Jacoby, 1978). Similarly, the second occurrence of an item presented in a random schedule would also necessarily receive more elaborate processing, due to the need to retrieve that item from long-term memory. Memory of the previous repetition is less accessible in a random or spaced presentation schedule, as there is interference between presentations from similar processing activities. Distributing presentations over time, whether in a spaced or random schedule, forces active reprocessing or cognitive reconstruction in working memory for each repeated item. In line with the levels of processing and deficient processing frameworks, this set of experiments provides

converging evidence that retention performance is then a function of the amount or quality of processing the item receives.

Carlson and Yaure (1990) used a math verification task in between trials in a blocked schedule to attempt to clear out working memory between repetitions of the rule. In the present study, *two* math verification problems were included; this was still not sufficient to create a random-like cognitive workload during study. Given the apparent difficulty of adding sufficient retrieval interference to a blocked schedule, it seemed reasonable to attack the problem from the other end by decreasing the amount of interference present in a random schedule. Experiment 3 included two new "semi-random" acquisition schedules, where participants learned the rules in groups of two or three, thereby reducing the amount of proactive interference during learning.

During the acquisition phase, the two- and three-rule groups responded more quickly than the random group, yet not as fast as the blocked group. However, the differences between groups lessened as participants had more practice at the task. The blocked group performed significantly faster across all blocks of the acquisition phase. While the performance of the two- and three-rule groups was stacked in-between that of random and blocked, as predicted by the "net interference" view, the means fell closer to that of the random group. Consistent with an intraitem processing view, it seems that a very similar and demanding task between repetitions of the rules (i.e. the retrieving of a similar rule to-be-learned), even with the limited uncertainty of the two-rule schedule, was enough to clear out working memory, forcing participants to reload the rule on every trial. In contrast to the blocked-plus-intervening-task schedule of Experiments 1 and 2, the two- and three-rule schedules involved an 'intervening task' with processing demands that mirror those of the main task. The similarity of procedural activity between

repetitions of rules forced the clearing out of working memory, leading to increased workloads for all these practice schedules as compared to a blocked schedule.

Since there were marginal effects of the number of rules learned at a time, one can theorize that the amount of proactive interference during learning may have some effect on final retention of that material as well. When learning rules in groups of two, participants only have to keep those two rules activated in memory at a time. The present results confirm that participants could not hold even two rules at once in working memory across trials; if this had been the case, acquisition results would have mirrored those of the blocked group. However, participants were quicker at responding to one of only two rules, and also made less errors, as opposed to when all six were being learned at once (pure random schedule). Similarly, when learning three rules simultaneously, reaction time and accuracy results fell in between that of the two-rule group and the random group. These differences in processing levels for the various practice schedules can be confirmed by looking at the retention results, where the opposite pattern is found. The deficient processing in the blocked schedule during acquisition led to dismal performance at retention; however, this was not the case for the two- and three-rule groups, who performed closer to the random schedule. Additionally, the differences in retrieval demands during learning for the two-rule, three-rule and random (six-rule) groups led to similar 'stacked' performance 48 hours later.

Another finding from these experiments concerns the reliability and generality of the contextual interference effect for cognitive procedures and rules. A strong contextual interference effect was found with different symbol sets (both related and unique symbols), and over replications with different subject pools. Participants in the first two experiments were first- or second-year undergraduates enrolled in an introductory

psychology class. Experiment 3 tested upper-level undergraduates enrolled in higher level cognitive and developmental psychology courses. The two sets of participants showed differences between blocked and random performance that were quite similar, with the upper-level students (Exp. 3) performing slightly faster and more accurately at retention. The use of different pools of participants adds to the generalizability of these results.

Investigations into the processing mechanisms of contextual interference remain few. In the present set of studies, intraitem processes of displacement of procedures from working memory (in all the random practice schedules, even with only two rules per block, but apparently not in the blocked-IT conditions) and proactive interference from other active rules (in the contrast between the two-, three- and six-rule blocks of experiment 3) appear to be most important, with little contribution of interitem, relational processing (seen in the minimal effects of the relational structure of materials in Experiment 2 versus Experiment 1, and the large contextual interference effect in the two-rule condition of Experiment 3). Of course, we have not ruled out the existence of relational processing altogether, as there may be other forms of relational processing taking place during learning. For example, even in the unrelated random condition (Exp. 1), participants may be comparing and contrasting the various rules and symbols, although explicit relations were not built into the stimuli. In order to learn things more efficiently, we have learned to utilize heuristics, mnemonic devices, imagery, and other forms of elaboration to better encode the materials to-be-learned. It makes sense, then, that learners would attempt to build relations into the list of rules and symbols, leading to more organized long-term structures.

As there was a slight effect of relational processing in Experiment 2, it might be interesting to test this further by adding a relational component to the semi-random schedules used in Experiment 3. For example, in an 'unrelated' two-rule condition, participants could learn two unique, unrelated rules. In a 'related' condition, the rules would alternate between two highly similar symbols with similar sequential math rules. Perhaps the set-wide organization that was present in Experiment 2 was not fully realized due to the rules being presented in a completely random order. Grouping the related rules could aid in creating the set-wide organization in participants' long-term memory structure, and thus lead to superior retention performance for the related group. Additionally, manipulating the correspondence between symbols and rules within the present task may help to determine if the benefit of relational processing lies with the retrieval of the symbols or implementation of the specific rules. More research into potential strategies for uncovering and investigating relational processing during learning is needed.

There may also be some merit to manipulating the predictability of the rules. Would there be a performance difference between two-rule groups where the rules were merely alternating versus "random"? There seem to be two main differences in cognitive processing between these groups. First, there is the opportunity to pre-load the alternate rule in working memory in the predictable group, as posited by Schneider et al. (1995). Of course, this necessarily rests on the notion that participants have enough time between trials, so that the opportunity for preloading can aid in decreasing the time to choose the correct rule. Second, the pairing between symbol and rule becomes less important and perhaps irrelevant in the predictable group, since participants can focus specifically on what rule to apply next and can effectively ignore the corresponding symbol.

It seems that predictability could lead to a slight decrease in response time during acquisition, however it may be that decreased encoding of the symbols would lead to depressed retention performance in this group. Unlike a blocked schedule, the two-rule schedule should still afford intraitem processing, since the participants will have to reinstate a new rule on each trial. This should lead to acquisition performance similar to the blocked condition, but perhaps with slightly longer latencies due to the added rule retrieval on each trial.

These results on the distribution and variability of practice can also be broadened to aid and direct research in training and educational settings. Training situations often are built around 'blocked' chapters or modules. If learners are forced to retrieve and reconstruct the new information more often, either by the spacing out of presentations across time or by random presentation, then based on converging evidence from the cognitive literature we can assume that there will be greater long-term retention of the material.

An interesting study by Landauer & Bjork (1978) investigated how retrieval practice should be organized and distributed across time to maximize long-term retention of information. Participants learned names of fictitious people in various presentation schedules. A name was presented once, and then tested three times with different presentation intervals. Participants who received zero items intervening between tests (massed practice) performed with the greatest accuracy during acquisition. Those who had four or five intervening names between tests performed much poorer during the acquisition phase. However, the exact opposite trend was found for a retention test given 30 minutes later. Landauer and Bjork found that an expanding sequence of repetitions (0,

1, 3, and 8 intervening tests) was the most effective training schedule for optimal retention performance.

As revealed by the literature on contextual interference, retrieval practice in a random schedule can lead to better performance on tests of retention. Giving learners a chance to retrieve the to-be-learned information at random intervals during acquisition, rather than in set blocks, modules or chapters, could be beneficial. To maximize long-term retention, the literature regarding the variability of practice should be incorporated into training materials and instructional texts to encourage random schedules of learning.

As previously stated, very few studies have looked at contextual interference in the learning and retention of cognitive skills, and this set of experiments has revealed a substantial contextual interference effect for a rather novel task of pairing symbols with sequential mathematical rules. These studies add to the growing literature that contextual interference effects can be found for more complex cognitive learning skills.

Theoretical explanations from the literature on the distribution of practice (e.g. deficient processing theories) can be beneficial to understanding underlying processes of random and blocked practice schedules; however, questions still remain regarding the contributions of intraitem and relational processing to the contextual interference effect. Substantial evidence of intraitem processing has been found here and elsewhere in the literature on practice and learning; however, more research is clearly needed on the relational aspects of contextual interference, and of skill learning in general. It seems likely that with more complex, structured material of the sort found in almost any formal academic domain, be it mathematical, scientific or philosophical, learning the relations, contrasts and organizational structure of that material would seem to be critical to

developing expertise in that domain; it may be that learning in this broader sense would show a much greater role played by the sort of relational processing that random practice affords.

APPENDIX A
SYMBOLS AND RULES FOR EXPERIMENT 1

図 (A, B, C) ----> [(A - C) + B]

兄 (A, B, C) ----> [(C * B) - A)]

同 (A, B, C) ----> [(B + A) - C)]

住 (A, B, C) ----> [(A - B) * C)]

買 (A, B, C) ----> [(B + C) * A]

友 (A, B, C) ----> [(C * A) + B)]

APPENDIX B
SYMBOLS AND RULES FOR EXPERIMENT 2

員 (A, B, C) ----> [(B + C) - A]

買 (A, B, C) ----> [(B + C) * A]

注 (A, B, C) ----> [(A - B) + C)]

住 (A, B, C) ----> [(A - B) * C)]

右 (A, B, C) ----> [(C * A) - B)]

友 (A, B, C) ----> [(C * A) + B)]

APPENDIX C
PREDICTED AND ACTUAL FUNCTIONS FOR EXPERIMENT

Predicted functions based on EXP 1 data:

Fit Results - Random (best fit)
log(Y) = -0.6663 * log(X) + 9.582

Fit Results - Blocked (best fit)
log(Y) = -0.2383 * log(X) + 8.536

Fit Results - Three-rule (predicted)
log(Y) = -0.441 * log(X) + 9.00

Fit Results - Two-Rule (predicted)
log(Y) = -0.3524 * log(X) + 8.791

Predicted Based on EXP 3 Random/blocked data:

Predicted Three-Rule:
log(Y) = -0.526314 * log(X) + 9.195

Predicted Two-Rule:
log(Y) = -0.435316 * log(X) + 8.992

Predicted retention functions based on EXP 1 data:

Fit Results - Random
Linear
Y = -0.742 * X + 5.907

Fit Results - Blocked
Y = -2.56 * X + 15.56

Fit Results - Three-Rule
Y = -1.65 * X + 10.73

Fit Results - Two-Rule
Y = -1.95 * X + 12.34

Actual functions from all 4 schedules in EXP 3:

Fit Results - Random
log(Y) = -0.7129 * log(X) + 9.647

Fit Results - Blocked
log(Y) = -0.1605 * log(X) + 8.424

Fit Results - Three-rule
log(Y) = -0.553 * log(X) + 9.426

Fit Results - Two-rule
log(Y) = -0.362 * log(X) + 9.176

Predicted Retention Based on EXP 3 Random/blocked data:

Predicted Three-rule
Y = -1.693 * X + 11.251

Predicted Two-rule
Y = -2.031 * X + 12.916

Actual Retention functions for EXP 3:

Fit Results - Random
Linear
Y = -0.677 * X + 5.579

Fit Results - Blocked
Y = -2.708 * X + 13.53

Fit Results - Three-Rule
Y = -1.378 * X + 8.02

Fit Results - Two-Rule
Y = -1.563 * X + 9.155

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BIOGRAPHICAL SKETCH

Nancy H. Lincoln was born in Palm Beach Gardens, Florida on February 22, 1972. She attended high school at Palm Beach Gardens High School, and graduated with honors in 1990. She received the Florida Undergraduate Scholar's Fund, and went to Stetson University for one year; but then chose to move to Gainesville and attend the University of Florida. She received her Bachelor of Science degree in psychology from UF in 1994, and after taking a year off to play and tour with her band, in August 1995 she began graduate school in the Department of Psychology at UF, concentrating on cognitive psychology. She received her Master of Science degree in May 1998 and will receive her Doctor of Philosophy degree in December 2001. In xx of 199x, she was awarded the E. Porter Horne Award for outstanding graduate student in Cognitive and Sensory Processes. From June - December of 1998, she was a usability engineer intern at Silicon Graphics in Mountain View, CA. The following summer she completed a three-month internship at Microsoft in Redmond, WA. Nancy has since accepted a position with Microsoft as a usability engineer and lives in downtown Seattle.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ira Fischler, Chair
Professor of Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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